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EMC Analysis of a Prototype Civil-Use GPS Receiver on Four Aircraft Configurations

Robert L. Mullen

IIT Research Institute
Under Contract to
Department of Defense

Electromagnetic Compatibility
Analysis Center
Annapolis, Md. 21402

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Consulting Report

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16. Abstract

The cosite electromagnetic compatibility aspects were evaluated for the simultaneous operation of a prototype civil-use GPS receiver and other avionic systems on board four specific aircraft configurations.

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METRIC CONVERSION FACTORS

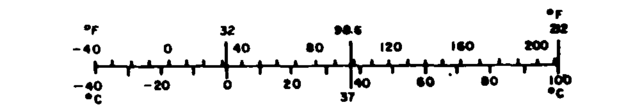
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

The Federal Aviation Administration has requested that the DoD Electromagnetic Compatibility Analysis Center evaluate the cosite electromagnetic compatibility aspects of the simultaneous operation of a prototype civil-use Global Positioning System receiver and other avionic systems on board four specific airborne platforms, using previously developed interference criteria. The four airborne platforms included specific configurations of a Boeing 747, a Boeing 727, and two Rockwell Aerocommanders.

The analysis for each aircraft addressed the potential of interference from adjacent-signal and out-of-band transmitters. Adjacent-signal transmitters aboard the four aircraft configurations consisted of Distance Measuring Equipment interrogators, Air Traffic Control Radar Beacon System transponders, Mode S transponders, and Traffic Alert and Collision Avoidance System interrogators. The out-of-band transmitters included HF, VHF, and UHF communications equipment. The electromagnetic compatibility aspects of the GPS receiver that were examined included burnout and saturation of the limiting diode in the receiver front end, interference to signal acquisition, and interference to signal code and carrier tracking. Only radiated interference coupled from the transmit antenna to the receive antenna was examined in this analysis. Conducted interference was not considered.

For the specific configurations analyzed, no potential instances of burnout or saturation of the limiting diode due to signals from individual or multiple on-board transmitters were identified.

For the specific configurations analyzed, no potential instances were identified in which the interfering signal from an individual on-board transmitter exceeded the GPS interference thresholds.

For the specific configurations analyzed, one potential instance was identified in which the composite interfering signal from multiple on-board transmitters exceeded the GPS interference threshold for C/A signal acquisition. Alternative actions were recommended to preclude the occurrence of interference to the GPS receiver.

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SECTION 1

INTRODUCTION

BACKGROUND

The Global Positioning System (GPS) is being developed by the GPS Joint Program Office of which the United States Air Force (USAF) is the lead service. It is expected to be fully operational by the mid 1980's and will consist of a system of satellite transmitters and user receivers for the purpose of ground, maritime, and aeronautical navigation. GPS uses two downlink frequency channels, L_1 and L_2, at 1575.42 MHz and 1227.6 MHz, respectively.

Navigational accuracy is dependent upon the type of receiver employed. Receivers capable of providing the most accurate positioning information will be available only to authorized users. These receivers receive both L_1 and L_2 frequency channels and process a precision (P) signal and a coarse/acquisition (C/A) signal. Receivers available to civil users will process only the C/A signal of Channel L_1 and will provide less accurate position data.

The Federal Aviation Administration (FAA) has requested that the DoD Electromagnetic Compatibility Analysis Center (ECAC) evaluate the electromagnetic compatibility (EMC) aspects of the FAA-developed experimental dual channel GPS receiver aboard four specific airborne platforms using previously developed interference criteria.

OBJECTIVE

The objective of this task was to evaluate the cosite EMC aspects of the simultaneous operation of a prototype civil-use GPS receiver and other avionic systems on board four specific aircraft configurations.

APPROACH

In this analysis, attention was directed toward potential cosite sources of interference to a prototype civil-use GPS receiver. The analysis was performed for the GPS receiver on board a Boeing 747, a Boeing 727, and two configurations of a Rockwell Aerocommander.

Information concerning antenna location and equipment characteristics for each on-board aircraft transmitter and the prototype GPS receiver was obtained from either the FAA, results of prior ECAC work, or manufacturer technical manuals.

No transmitters were identified in the four aircraft configurations that operate cochannel or in-band with the GPS receiver frequency. Therefore, the EMC analysis for each aircraft addressed the potential of interference from adjacent-signal and out-of-band transmitters. Only radiated interference coupled from the transmit antenna to the receive antenna was examined in this analysis. Conducted interference was not considered. Adjacent-signal transmitters aboard the four aircraft configurations consisted of Distance Measuring Equipment (DME) interrogators, Air Traffic Control Radar Beacon System (ATCRBS) and Mode S transponders, and Traffic Alert and Collision Avoidance System (TCAS) interrogators. The out-of-band transmitters included HF, VHF, and UHF communications equipment.

The potential of interference to the GPS receiver from adjacent-signal transmissions was considered first. The peak and average effective on-tune undesired-signal power levels that each adjacent-signal transmitter could present to the GPS receiver were calculated. The technical parameters involved in these calculations included maximum transmitter peak power, transmitter duty cycle, the gains of both the transmitter and GPS receiver antennas, frequency-dependent rejection (FDR), and the path loss due to the separation of the transmitter and receiver antennas.

The technical parameters are listed in APPENDIX A for the transmitters that were examined in this analysis. The GPS antenna gain was obtained from information provided by the FAA.[1] The GPS receiver selectivity, obtained from the Massachusetts Institute of Technology (MIT) Lincoln Laboratory (LL),[2] was used in conjunction with the transmitter emission spectrum to derive values for FDR.

FDR is the rejection experienced by the undesired emission as a result of the limited bandwidth of a receiver as well as any off-tuning of the rece[illegible] frequency with respect to the transmitter tuned frequency. For each transmitter, FDR was evaluated at the closest possible tuned frequency to [illegible] GPS receiver frequency.

Propagation losses between the transmit antennas and the GPS antenna were determined by application of either the Avionics Interference Prediction Model (AVPAK)[3] or the procedure described in an ECAC report entitled Path Loss Prediction for Irregularly Shaped Airframes.[4]

The calculated transmitter power level at the GPS receiver input was compared with interference power criteria provided by the FAA.

The HF, VHF, and UHF communication transmitters were analyzed as potential sources of harmonic and spurious-emission interference. These transmitters are multichannel and can be tuned to subharmonics of the GPS receiver frequency. Values for transmitter harmonic and spurious attenuation

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[1] FAA/ARD-452 letter of 20 April 1981, subject: Data Items for EMC Analysis of GPS T&E Systems.

[2] MIT LL/Group 42 letter of 9 July 1981, subject: Selectivity of the FAA GPS Receiver.

[3] A Model to Predict Mutual Interference Effects On An Airframe, FAA-RD-76-50, FAA, Washington, DC.

[4] King B., Path Loss Prediction for Irregularly Shaped Airframes, ECAC-TN-76-004, ECAC, Annapolis, MD February 1976.

are shown in APPENDIX A. The antenna gains for the HF, VHF, and UHF transmitters at the GPS frequencies were assumed to be 0 dBi.

Calculations were also made to determine if the burnout protection limiter in the front end of the GPS receiver could be damaged or saturated by emissions from transmitters on board the aircraft.

SECTION 2
ANALYSIS

GENERAL

The analysis that follows is general in nature and applies to all of the aircraft. Appendixes following the main body of the report relate the analysis specifically to each aircraft configuration. The MIT LL Aerocommander analysis is contained in APPENDIX B, the FAA Technical Center Boeing 727 analysis is in APPENDIX C, the analysis of the Boeing 747 is in APPENDIX D, and the FAA Technical Center Aerocommander analysis is in APPENDIX E.

Interference from aircraft search radars, Doppler radars, and radar altimeters was not analyzed in detail because the frequencies of these devices were much higher than the GPS frequency. Potential interference from the search and Doppler radars via local oscillator leakage is not possible because the GPS L1 carrier frequency is below the waveguide cutoff frequencies of the radars. Radar altimeters on these aircraft do not generate any frequency closer than approximately 1 GHz from the GPS frequency. Therefore, these three types of radar equipment will not interfere with GPS operation.

Interference caused by spurious receiver responses is not expected to occur. Spurious receiver responses arise when strong undesired signals and the receiver local oscillator signal combine in the mixer to produce a frequency on, or near, the receiver intermediate frequency. In the GPS receiver, the selectivity of the preamplifier effectively limits the number of spurious frequencies that must be considered. None of the avionics transmitters examined in this analysis produce strong undesired signals at frequencies that could cause spurious responses in the GPS receiver.

Saturation of the GPS receiver preamplifier or downconverter will not occur for the four aircraft configurations examined in this analysis. Figure 1 is a block diagram of the prototype civil-use GPS receiver front-end

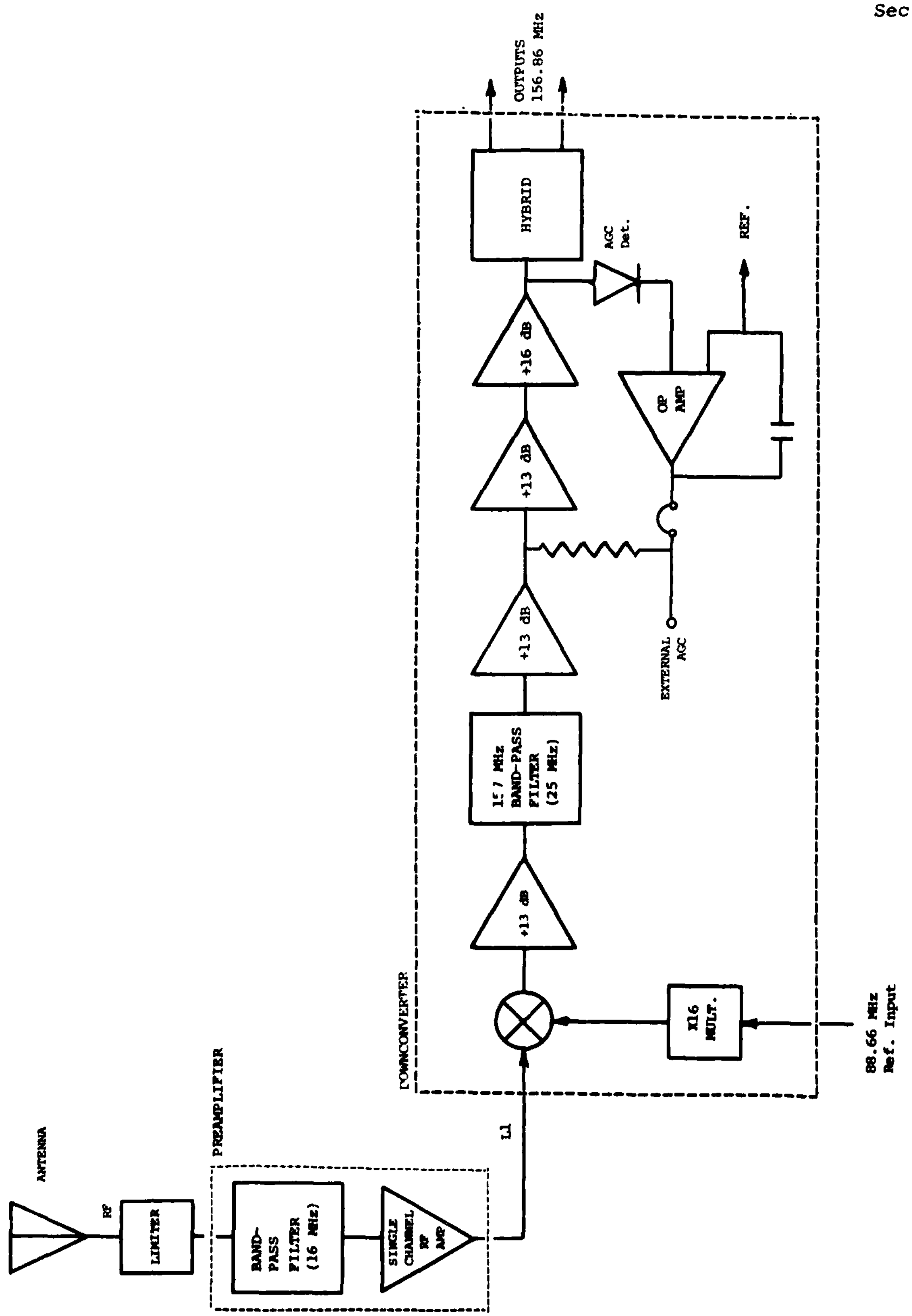

Figure 1. Block diagram of the prototype civil-use GPS receiver front-end.

obtained from Reference 2. The input power levels that will saturate the limiter, the preamplifier, and the downconverter were given in Reference 1 as +15 dBm, -38 dBm, and -45 dBm, respectively. As previously stated, there are no transmitters in the four aircraft configurations that operate in-band with the GPS receiver. The transmitters that tune closest to the GPS L1 frequency are the DME, ATCRBS, Mode S, and TCAS transmitters which are tuned 425 (min), 485, 485, and 545 MHz, respectively, below the GPS L1 frequency. In the GPS receiver preamplifier, filtering is used prior to amplification in order to select the GPS L1 signal while rejecting out-of-band interference. The selectivity of the preamplifier band-pass filter, obtained from Reference 2, is shown in Figure 2. FDR values were calculated using the preamplifier selectivity and the DME, ATCRBS, Mode S, and TCAS transmitter emission spectrums. The minimum FDR value was 68 dB. Therefore, if the interfering signal from any one of these transmitters has not saturated the limiter (i.e., $P_R \leq +15$ dBm), then the effective interfering signal power level at the input of the preamplifier will be $I_{PA_{eff}} \leq +15 - 68 = -53$ dBm. This is 15 dB below the preamplifier input saturation threshold of -38 dBm.

The preamplifier amplifies the GPS L1 signal by 50 dB and may increase the interfering signal too; however, the gain will be less than 50 dB. The interfering signal level at the input to the downconverter from any one of the adjacent-band transmitters will be $I_{DC} < -53 + 50 = -3$ dBm. The selectivity of the band-pass filter in the downconverter, obtained from Reference 2, is shown in Figure 3. FDR values were determined using the downconverter selectivity and the DME, ATCRBS, Mode S, and TCAS signal spectrums. The minimum FDR value was 64 dB. Therefore, the effective interfering signal power level at the input of the downconverter will be $I_{DC_{eff}} \leq -3 - 64 = -67$ dBm. This is 22 dB below the downconverter input saturation threshold of -45 dBm.

Therefore, for the four aircraft configurations analyzed, the preamplifier and the downconverter will not experience saturation.

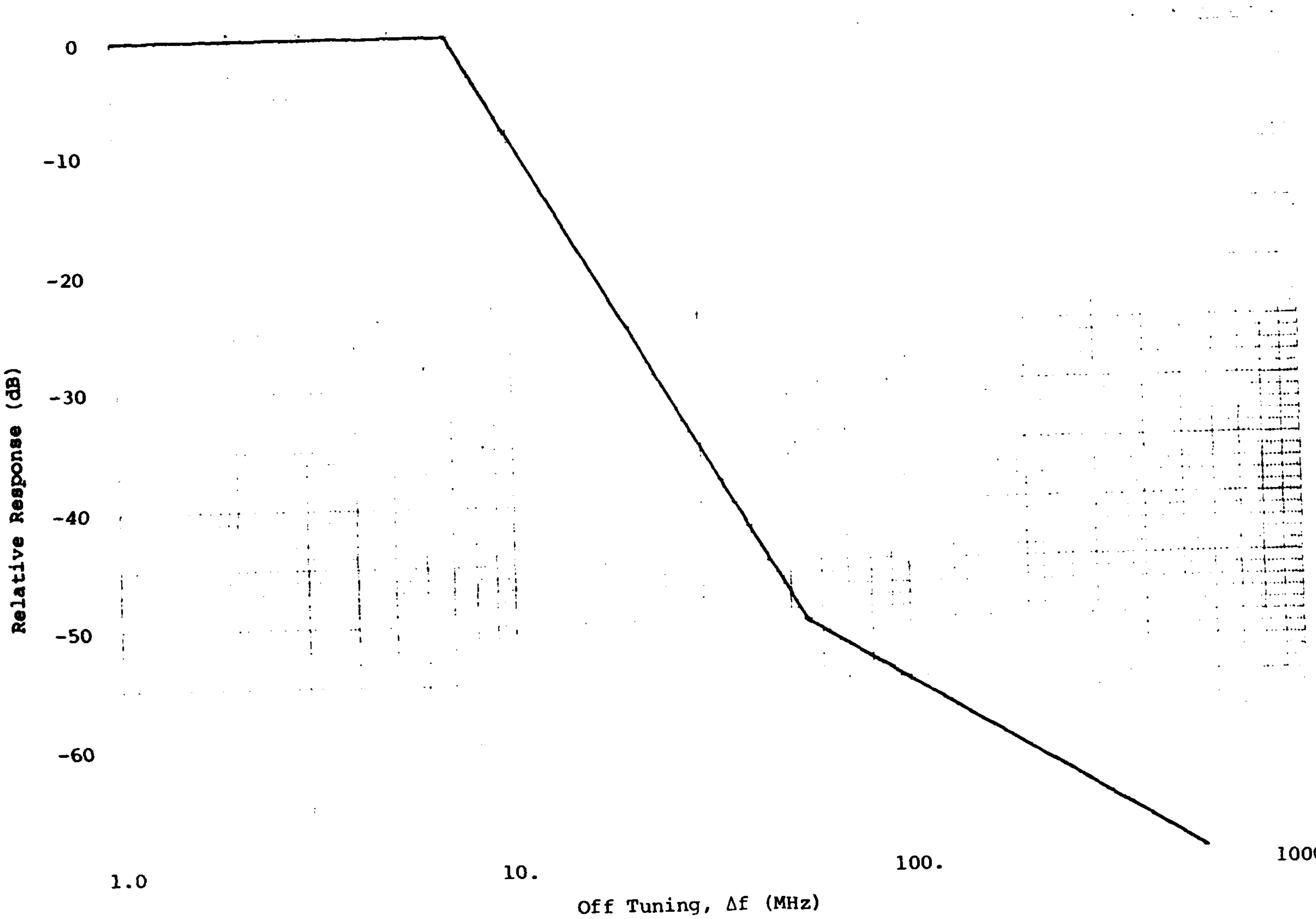

Figure 2. GPS receiver preamplifier selectivity.

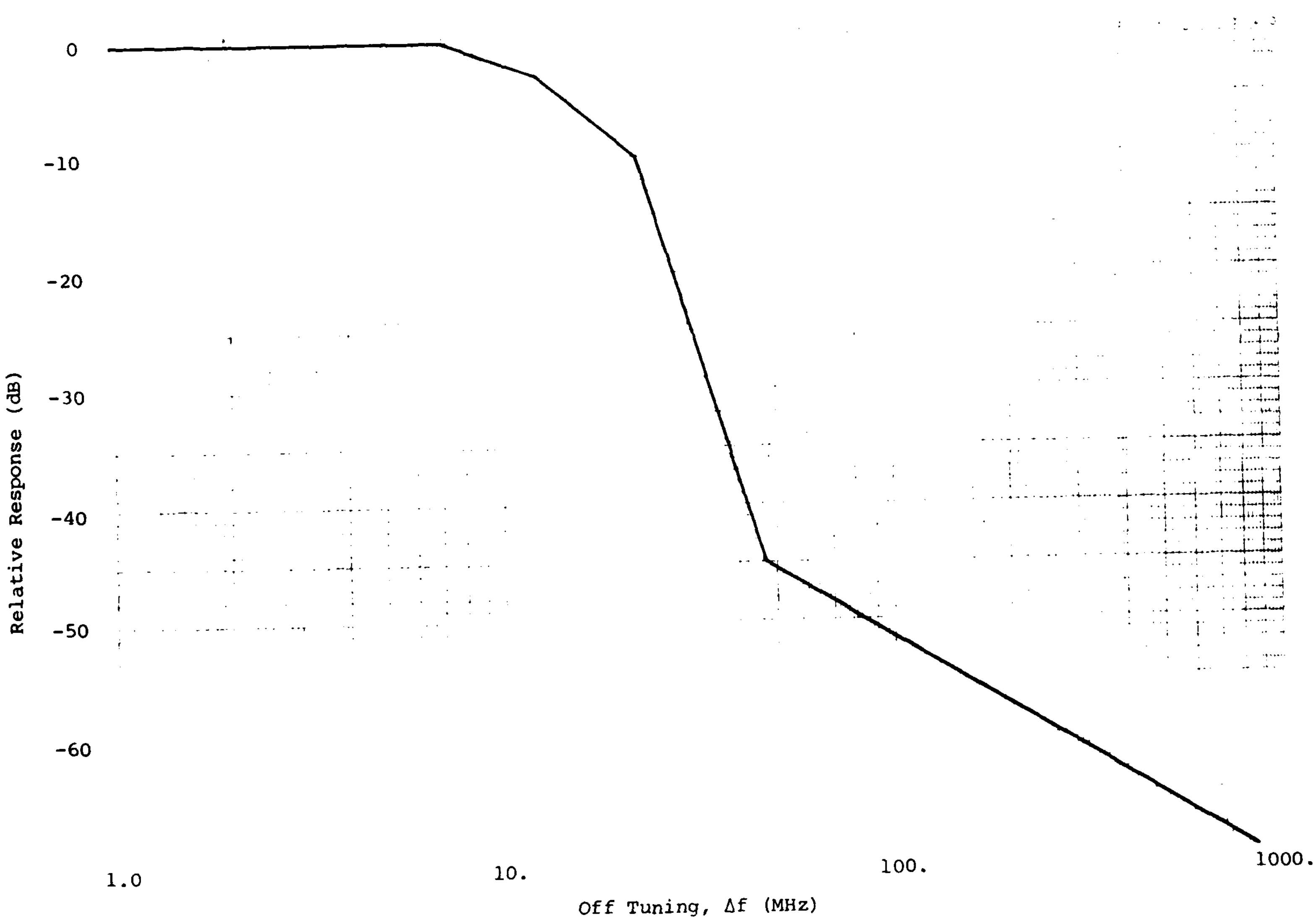

Figure 3. GPS receiver downconverter selectivity.

ANALYSIS

GPS Receiver Interference Criteria

The methods discussed below were used to calculate an equivalent on-tune average power level, from each on-board transmitter, for comparison with the GPS interference thresholds. These thresholds represent the jamming powers which will prevent acquisition and cause loss of lock. Receiver measurements performed at Lincoln Laboratory showed that a minimum carrier-to-noise spectral density ratio (C/N_O) for signal acquisition is 35 dB-Hz and that loss of lock will occur at 33 dB-Hz. The recommended GPS interference thresholds, including margins to account for manufacturing tolerances and aging are:[5]

	C/N_O	Maximum Jamming Level
Minimum for acquisition	37 dB-Hz	-109 dBm
Loss of Lock	34 dB-Hz	-106 dBm

The GPS specification (Reference 1) does not indicate any frequency dependence for burnout or saturation of the feedback limiting diode that precedes the preamplifier. The burnout and saturation limits (from Reference 1) used are:

Burnout	+37 dBm	CW power
	+55 dBm	Peak power
Saturation	+15 dBm	Peak power

Four types of potential interference were considered in the analysis: adjacent-signal interference, out-of-band transmitter interference, saturation, and burnout.

[5]MIT LL/Group 42 letter of 17 May 1982, subject: Review comments for draft report ECAC-CR-82-048.

Adjacent-signal Interference

In the analysis of adjacent-signal interference conducted for the four civil aircraft configurations, the effect of emissions from DME, ATCRBS, Mode S, and TCAS transmitters on the GPS receiver was considered. Calculations were also performed to determine the effect of CW leakage from these transmitters. The maximum allowable CW output powers for DME (-47 dBm), ATCRBS (-40 dBm), Mode S (-50 dBm), and TCAS (-60 dBm) were used for these calculations. CW emissions from these transmitters will not affect the GPS receiver operation.

For each potential interference case, the peak and average effective on-tune interference power levels referenced to the input of the GPS receiver were calculated. The parameters used in the calculation of effective on-tune interference power level were transmitter output power, transmitter and receiver antenna gains, transmitter duty cycle, frequency-dependent rejection, and path loss. Transmitter maximum power was used in this analysis. Antenna gains for the interference sources were obtained from the ECAC data base.

FDR depends on the detuning between a transmitter and a receiver, and is the rejection provided by a receiver to a transmitted signal as a result of both the limited bandwidth of the receiver with respect to the emission spectrum and the specified detuning. FDR was calculated using the bounds on the transmitter emission spectrum, the GPS receiver selectivity, and the minimum frequency separation. A detailed description of FDR is contained in APPENDIX F.

The effects of shielding by the aircraft fuselage, wings, and engine pods, where applicable, were taken into consideration in the path-loss calculations. Equation 1 was used to calculate the peak effective on-tune interference power at the input to the GPS receiver:

$$P_R = P_T + G_T + G_R - FDR - L_P \qquad (1)$$

where

P_R = peak effective on-tune interference power at the receiver, in dBm

P_T = peak transmitter output power, in dBm

G_T = transmitter antenna gain, in dBi

G_R = receiver antenna gain, in dBi

FDR = frequency-dependent rejection, in dB

L_p = path loss (calculated at the transmit frequency), in dB.

The average effective on-tune interference power at the input to the GPS receiver was calculated using Equation 2 and the results of Equation 1:

$$P_A = 10 \log \left(\frac{dc}{100}\right) + P_R \qquad (2)$$

where

P_A = average effective on-tune interference power at the receiver, in dBm

dc = the duty cycle expressed as a percentage

and P_R was defined previously.

The average interfering signal power was compared with the GPS interference thresholds in order to determine whether or not the potential for interference existed.

Out-of-band Transmitter Interference

Potential in-band interference from out-of-band transmitters was considered for each aircraft by examining the particular communication equipment on board. The potential of interference was evaluated by calculating the maximum power level that each transmitter could present to the GPS receiver and comparing it to the interference power level criteria.

Possible harmonic and spurious power levels were calculated using Equation 3. Transmitter antenna gains were considered to be 0 dBi. The harmonic and spurious emission was assumed to be on tune to the GPS receiver.

$$P_R = P_T + G_T + G_R - A - L_p \qquad (3)$$

where

P_R[a] = average effective on-tune interference power at the GPS receiver input, in dBm

P_T[a] = maximum average transmitter output power, in dBm

A = harmonic or spurious attenuation with respect to the fundamental, in dB

L_p = path loss (calculated at the GPS receive frequency), in dB

and G_T and G_R were defined previously.

Saturation/Burnout Calculations

The feedback limiting diode is the first nonlinear device a signal encounters when entering the GPS receiver and is designed to protect the RF preamplifier from burnout. There is effectively no filtering in the GPS receiver before this limiter. The limiting diode can tolerate CW power at 5 watts (+37 dBm) and peak power at 300 watts (+55 dBm) without being damaged. Input power levels between 32 mW (+15 dBm) and 5 watts will drive the limiting diode into saturation.

Equation 4 was used to determine the maximum peak received power from on-board transmitters for comparison with the GPS receiver saturation and peak burnout thresholds:

---

[a]For the communication equipment considered in this analysis, the peak and average power levels are identical.

$$P_R = P_T + G_R + G_T - L_p - L_m \quad (4)$$

where

L_m = the antenna mismatch loss, in dB

and P_R, P_T, G_R, G_T, and L_p were defined in Equation 1. P_R was compared with the GPS saturation threshold (+15 dBm) and the peak power burnout threshold (+55 dBm) in order to determine whether or not the potential for burnout or saturation existed.

The antenna mismatch losses between the GPS antenna and the out-of-band transmitter antennas were obtained empirically.[6] The mismatch losses are shown in TABLE 1.

TABLE 1

ANTENNA MISMATCH LOSSES

Aircraft Transmitter	Minimum Transmitter/Receiver Antenna Mismatch Loss (dB)
UHF Communication Radio	14
VHF Communication Radio	31
HF Communication Radio	60

Average received power, for comparison with the average power burnout threshold (+37 dBm), was calculated using Equation 2.

[6]McCubbins, R., and Craig, D., EMC Analysis of the Global Positioning System Aboard Four Development Test and Evaluation Aircraft, ESD-TR-77-001, ECAC, Annapolis, MD, February 1977.

Simultaneous Operation of Multiple Transmitters

Equation 5 was used to calculate the signal level at the input to the GPS receiver due to multiple transmitters operating simultaneously:

$$P_m = 10 \log \sum_{i=1}^{N} 10^{\left(\frac{P_i}{10}\right)} \qquad (5)$$

where

P_m = the total average input power, in dBm

P_i = the average input power, in dBm, for the ith transmitter.

P_m was compared with the GPS interference thresholds (+3[illegible] dBm for burnout, +15 dBm for saturation, -109 dBm for C/A signal acquisition, and -106 dBm for C/A signal code and carrier tracking).

SECTION 3
CONCLUSIONS AND RECOMMENDATION

GENERAL

The cosite EMC of the simultaneous operation of a prototype civil-use GPS receiver and other avionic systems was evaluated for the GPS receiver on board a Boeing 747, a Boeing 727, and two configurations of a Rockwell Aero-commander. The EMC aspects that were examined included burnout and saturation of the limiting diode, preamplifier, and downconverter, interference to C/A signal acquisition, and interference to C/A signal code and carrier tracking.

CONCLUSIONS

No potential instances were identified of burnout or saturation of the limiter, the preamplifier, or the downconverter due to signals from individual or multiple on-board transmitters.

No potential instances were identified in which the interfering signal from an individual on-board transmitter exceeded the interference thresholds for C/A signal acquisition or for C/A signal code and carrier tracking. However, in one case (i.e., the VHF #2 harmonic signal presented to the GPS #2 on the FAA Technical Center Aerocommander), the predicted interfering signal level is equal to the interference threshold for C/A signal acquisition (-109 dBm).

One potential instance was predicted in which the interfering signals from multiple on-board transmitters combined to produce an interfering signal level that exceeded the interference threshold for C/A signal acquisition. This case involved a harmonic signal from the VHF #2 transmitter and the noise skirts of the Mode S transmitter emission received simultaneously by the GPS #2 receiver on board the FAA Technical Center Aerocommander. The combined interfering signal level was -108 dBm; 1 dB above the interference threshold. Therefore, the simultaneous operation of the VHF #2 transceiver

and the Mode S interrogator may prevent the GPS #2 receiver from acquiring the signal from satellites until the elevation angle has increased to more than 5° above the horizon.

RECOMMENDATION

To preclude potential interference to the GPS receiver on board the FAA Aerocommander, it is recommended that either of the following two actions be implemented.

1. Do not use GPS #2 (Antenna #4, in Figure E-1). Instead, limit GPS operation to GPS #1 (Antenna #3 in Figure E-1).

2. Relocate the VHF #2 antenna so that it is separated by a minimum of 3 feet from both of the GPS antennas.

APPENDIX A

AVIONICS EQUIPMENT

GENERAL

The various avionics comprising the aircraft environment are shown on the antenna layout drawings in APPENDIXES B through E. The function, technical characteristics, and analysis parameters of each avionic equipment are presented in the following paragraphs. ARINC characteristic specifications shown in the tables listing equipment parameters are provided as information to the reader.

HIGH-FREQUENCY TRANSCEIVER

The airborne high-frequency transceiver, which provides long-range air-ground communications, transmits and receives amplitude modulated (AM) double-sideband, and single-sideband, voice signals. The transceiver characteristics are shown in TABLE A-1.

VHF TRANSCEIVER

The VHF transceiver provides normal air-ground voice communications. Each of the four aircraft has more than one VHF transceiver. Usually one is used for air-traffic control (ATC), one is used for company operations, and one is an optional back-up transceiver. The technical characteristics are shown in TABLE A-2.

UHF TRANSCEIVER

The UHF band (225 - 400 MHz) is used primarily by the military services. However, the frequency 243 MHz is utilized by government and non-government agencies for survival and rescue purposes. The frequency band from 328.6 MHz to 335.4 MHz is limited to Instrument Landing System (ILS) operation. The UHF band may be used for communications or for direction-finding purposes. If the transceiver is being used for direction-finding purposes, then only the receiver will be used. The transceiver characteristics are given in TABLE A-3.

TABLE A-1

HF TRANSCEIVER CHARACTERISTICS

	ARINC No. 533A[a]	Collins 618-T-2[b]
Frequency range (MHz)	2-30	2-30
No. of channels		28,000
Peak envelope power (PEP) output (W)		
Single-sideband	400	400
Amplitude modulation		125
Harmonic attenuation (dB)		
Minimum	40	d
At L1 frequency	d	120[c]
Spurious attenuation (dB)		
Minimum	60	d
At L1 frequency	d	120[c]
Antenna fundamental gain (dBi)	d	3.0

[a] Airborne HF SSB/AM System, ARINC Characteristic No. 533A, Aeronautical Radio, INC, Annapolis, MD, March 1966.

[b] 618T-1, 618T-1B, 618T-2, 618T-2B, 618T-3, and 618T-3B Airborne SSB Transceivers, 520-5970004-A01114, Collins Radio Company, Cedar Rapids, Iowa, October, 1968.

[c] Assumed values.

[d] Not available.

TABLE A-2

VHF TRANSCEIVER CHARACTERISTICS

	ARINC No. 546[a]	NARCO MK-24[i]	KING KTR-900[c]	BENDIX RTA-42A[d]	KING KTR-9100[e]	BENDIX RTA-41A[f]	COLLINS VHF-20[g]
Frequency range (MHz)	118-135.975	118-135.950	118-135.975	116-149.975	118-135.975	118-135.975	117-135.975
No. of channels	720	180	760	1360	720	720	720
Modulation	AM	AM	AM	AM	AM/FM	AM	AM
Power Output (W)	25-50	6	25	25	25	25	20
Harmonic attenuation (dB)							
Minimum	59	h	60	60	60	h	60
At L1 frequency	h	120[b]	120[b]	120[b]	120[b]	120[b]	120[b]
Spurious attenuation (dB)							
Minimum	79	h	90	100	110	h	90
At L1 frequency	h	120[b]	120[b]	120[b]	120[b]	120[b]	120[b]
Antenna							
Fundamental gain (dBi)	3	2.1	2.1	2.1	2.1	2.1	2.1
Polarization	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical

[a]Airborne VHF Communications Transceiver System, ARINC Characteristic No. 546, Aeronautical Radio, Inc., Annapolis, MD, October 1961.

[b]Assumed values.

[c]KTR-900 VHF Communications Transceiver, 006-5006-00, King Radio Corporation, Olathe, Kansas, April 1968.

[d]RTA-42A VHF Transceiver, I.B. 1142A-1 (23-23-2), Bendix Avionics Division, Ft. Lauderdale, FL, December 1973.

[e]KTR 9100 VHF Communications Transceiver Overhaul Manual, 006-5046-02, King Radio Corporation, Olathe, Kansas, February 1970.

[f]RTA-41 VHF Communications Systems, I.B. 1141A, Bendix Radio Division, Baltimore, MD, April 1968.

[g]VHF-20 Communications System, VSMF-0651, Collins General Aviation Division, Rockwell International, Cedar Rapids, Iowa, October 1978.

[h]Not available.

[i]Nominal characteristics obtained from the ECAC data base.

TABLE A-3

UHF TRANSCEIVER CHARACTERISTICS

	Collins AN/ARC-159[b]
Frequency range (MHz)	225. - 399.975
Modulation	AM
Power output (W)	10
Harmonic attenuation (dB)	
Minimum	60
At L1 frequency	100[a]
Spurious attenuation (dB)	
Minimum	60
At L1 frequency	100[a]
Antenna	
Fundamental gain (dBi)	3
Polarization	Vertical

[a]Assumed values.

[b]Radio Set AN/ARC-159, Technical Manual NAVAIR 16-30 ARC159-1, Collins Radio Group/Rockwell International, June 1976.

DME INTERROGATOR

Distance-measuring equipment provides the pilot with the slant-range distance from the aircraft to a selected DME ground facility. The airborne unit converts elapsed time to distance by measuring the length of time between the transmission of an interrogation to the selected ground station and the reception of the reply signal. The interrogator technical characteristics are given in TABLE A-4.

ATCRBS TRANSPONDER

The airborne air-traffic control transponder receives coded interrogations from a ground interrogator and responds by transmitting coded replies. The coded replies contain pilot-selectable identification codes and automatic-altitude codes depending on the mode of interrogation received. The transponder characteristics are given in TABLE A-5.

Mode S TRANSPONDER

The Mode S, which is being developed, is designed to be an improved secondary radar system with an integrated two-way data link. Mode S will differ from ATCRBS in the manner of selecting which aircraft will respond to an interrogation. In ATCRBS, the selection is spatial; in Mode S, each aircraft will be assigned a unique address code. Thus, an interrogator will be able to limit responses to its interrogations to those targets for which it will have surveillance responsibility, and to time the interrogations to ensure that the responses do not overlap. The Mode S transponder technical characteristics are given in TABLE A-6.

TCAS INTERROGATOR

The TCAS, which is being developed, is designed to be an active airborne collision avoidance system that will transmit interrogations to elicit replies from cooperating transponders. TCAS will utilize two signal formats, one that

TABLE A-4

DME INTERROGATOR CHARACTERISTICS

	ARINC No. 568[c]	NARCO DME-195[d]	KING KN-63[e]	KING KDM-7000[f]	COLLINS 860E-3[g]	KING KN-65[h]
Frequency Range Transmit (MHz)	1025-1150	1025-1150	1025-1150	1025-1150	1025-1150	1025-1150
Channel Spacing (MHz)	1	1	1	1	1	1
Peak output power (dBW)	30±3	20	30	30	30	30
Pulse width (μs)	3.5 (±.5)	3.5	3.5	3.5	3.5	3.5
Interrogation rate, maximum (pulse pairs per second)	150	150	150	144	150	150
Duty Cycle[a], maximum (%)	0.105	0.105	0.105	0.1008	0.105	0.105
Emission Bandwidth[a] (MHz)						
@ - 3 dB level	i	0.15	0.15	0.15	0.15	0.15
@ -20 dB level	i	0.52	0.52	0.52	0.52	0.52
@ -60 dB level	i	5.2	5.2	5.2	5.2	5.2
Spurious attenuation (dB)						
Minimum	i					
At L1 frequency	i	b	b	b	b	b
Antenna						
Fundamental Gain (dBi)	3	2.1	2.0	2.1	2.1	2.1
Polarization	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical

[a]Calculated

[b]Measured data on a military unit (Spectrum Signature of Radio Set AN/ARN-65, Technical Report ESG-TR-67-12, March 1967) comparable to DME were reviewed. All spurious emissions more than 130 MHz above the fundamental were harmonics. Therefore, no significant spurious emissions are expected near the L1 frequency.

[c]Mark-3 Airborne Distance Measuring Equipment, ARINC Characteristic No. 568, Aeronautical Radio, Inc., Annapolis, MD, February 9, 1968.

[d]Distance Measuring Equipment UDI-2A Interrogator, Maintenance Manual MM-03313-0600, National Aeronautical Corporation, Fort Washington, Pennsylvania, January 1976.

[e]KN-63 Digital DME System, MM-006-8313-01, King Radio Corporation, Olathe, Kansas, January 1980.

[f]KDM 7000 Digital DME System, VSMF-1469, King Radio Corporation, Olathe, Kansas, January 1980.

[g]860E-3 DME, 523-0762873-411113, Collins Radio Company, Cedar Rapids, Iowa, November 1975.

[h]KN-65/65A Distance Measuring Equipment, MM-006-5045-06, King Radio Corporation, Olathe, Kansas, September 1971.

[i]Not available.

TABLE A-5
ATCRBS TRANSPONDER CHARACTERISTICS

	ARINC No. 572[e]	Wilcox 814 B[f]	Collins 621 A-6[g]	Bendix TRA-63A[h]
Frequency (transmit) (MHz)	1090	1090	1090	1090
Peak power output (dBW)	27 to 30	27	27	30
Reply rate, maximum (replies per second)(one reply consists of 2 to 15 pulses)	2000	2000	2000[a]	2000[a]
Maximum duty cycle (%)	1.65[b]	1.35[b]	1.35[c]	1.35[b]
Pulse duration (μs)	0.35-0.55	0.45	.35-.55	.35-.55
Emission bandwidth (MHz)				
@ - 3 dB level	i	1.9	1.2	3.6
@ -20 dB level	i	12.8	6.6	11.0
@ -60 dB level	i	128	66	110
Spurious attenuation (dB)				
Minimum	60	60	60	i
At L1 frequency	i	d	d	d
Antenna				
Fundamental gain (dBi)	3[a]	3.0	2.1	2.1
Polarization	Vertical	Vertical	Vertical	Vertical

[a]Assumed values.

[b]Calculated value.

[c]By FAA direction, a value of 1.35% was used for the ATCRBS on the Boeing 727.

[d]Measured data on a comparable military transponder (Spectrum Signature of Transponder Set AN/APX-25, RADC-TDR-63-362, Bendix Field Engineering Corp., 28 February 1964) indicate that all spurious emissions are harmonics. Transponder harmonics do not occur near the L1 frequency.

[e]Mark 2 Air Traffic Control Transponder, ARINC Characteristic No. 572, Aeronautical Radio Inc., Annapolis, MD, September 3, 1968.

[f]Instruction Manual for Transponder Model 814B, Manual No. 104905-300, Wilcox Aviation Electronics, Kansas City, Missouri, March 1969.

[g]621 A-6 ATC Transponder, 523-0756695-00111B, Collins Radio Company, Cedar Rapids, Iowa, October 1967.

[h]TRA-63 ATC Transponder System, I.B. 1061A, Bendix Radio Division, Baltimore, MD, January 1968.

[i]Not available.

TABLE A-6

MODE S TRANSPONDER CHARACTERISTICS

	U.S. National Standard[d]	Bendix TRU-2[e]
Frequency (transmit) (MHz)	1090	1090
Peak power output (dBW)	27	27
Pulse width (μs)	0.5/1.0	0.5/1.0
Duty cycle, long term (%)	1.0	1.0[a]
Emission bandwidth[g] (MHz)		
@ - 3 dB level	2.6	1.7[b]
@ -20 dB level	14.	12.8[b]
@ -40 dB level	46.	38.[b]
@ -60 dB level	156.	120.[b]
Spurious attenuation (dB)		
Minimum	60	60
At L1 frequency	f	105[c]
Antenna		
Fundamental gain (dBi)	3	2.1
Polarization	Vertical	Vertical

[a]Duty cycle supplied by FAA.

[b]Calculated.

[c]Assumed value.

[d]U.S. National Aviation Standard For The Discrete Address Beacon System, FAA Order 6365.1, U.S. Department of Transportation, Federal Aviation Administration, Systems Research & Development Service, Washington, D.C. December 9, 1980.

[e]TRU-2 DABS/ATC Transponder System, I.B. 1171A, Bendix Avionics Division, Ft. Lauderdale, FL, December 1980.

[f]Not available.

[g]The DABS [Mode S] National Standard values do not include a ±3 MHz reply frequency tolerance.

is compatible with the ATCRBS signal format and one that is compatible with the Mode S signal format. TCAS is intended to provide the collision avoidance function in a mixed environment of Mode S and ATCRBS transponder-equipped aircraft. The interrogator technical characteristics are presented in TABLE A-7.

TABLE A-7

TCAS INTERROGATOR CHARACTERISTICS

	FAA Engineering Requirement[b]
Frequency (transmit) (MHz)	1030
Peak power output (dBW)	30
Pulse width (μs)	0.8/1.6 (ATCRBS) 0.8/16.25/30.25 (Mode S)
Duty cycle, long term (%)	0.1[a]
Emission bandwidth (MHz)	
@ - 3 dB level	6
@ -20 dB level	21
@ -40 dB level	67
@ -60 dB level	210
Spurious attenuation (dB)	
Minimum	120
At L1 frequency	>120
Antenna	
Fundamental gain (dBi)	2.1[c]
Polarization	Vertical

[a]Value provided by FAA.

[b]Engineering Requirement for the Active Beacon Collision Avoidance System, FAA-ER-250-2, Department of Transportation, Federal Aviation Administration, Systems Research & Development Service, Washington, DC, July 18, 1979.

[c]Value assumed. FAA-ER-250-2, Section 3.2.3 states that the antenna pattern shall be essentially omnidirectional or have a slight gain in the forward direction

APPENDIX B

GPS EMC ANALYSIS FOR THE MIT LL AEROCOMMANDER

C-E SYSTEMS CONFIGURATION

The Rockwell Aerocommander is a business and executive transport type of aircraft. Typically, it will accommodate up to seven passengers and two crew members. Figure B-1 shows the MIT LL configuration of the Aerocommander as described in Reference 1 and confirmed in a telephone conversation[7] with Dr. Campbell of MIT LL in November 1981. The antenna locations are shown in this figure and the equipment attached to each antenna is identified. The C-E transmitter equipment complement of concern consists of two VHF radios, two DME interrogators, and one Air Traffic Control Radar Beacon System (ATCRBS) transponder.

GPS INSTALLATION DESCRIPTION

The GPS system configuration on board the MIT LL Aerocommander consists of the prototype civil-use GPS receiver attached to a right-hand circularly polarized antenna, Model CA-3224, manufactured by Chu Associates, Inc. The antenna is located on the top, center of the aircraft fuselage, approximately 119" (302 cm) aft of the aircraft nose. Figure B-2 shows the gain versus elevation angle characteristic of the antenna over a 7' (213 cm) by 10' (305 cm) ground plane. The antenna is omnidirectional in azimuth.

ADJACENT-SIGNAL ANALYSIS

The adjacent-signal analysis conducted for the MIT LL configuration of the Aerocommander focused attention on possible interference to GPS operation due to on-board DME and ATCRBS transmissions. The two DME antennas and the ATCRBS antenna are all located on the bottom center of the aircraft fuselage.

[7]TELCON between R. Mullen, ECAC and Dr. S. Campbell, MIT Lincoln Labs, 5 November 1981.

No.	ID	Equipment Type	Z-Distance[a]	Top/Bottom
1	GPS	Prototype	119.	Top
2	VHF #1	NARCO MK-24	161.	Top
3	VHF #2	King KTR-900	260.	Top
4	DME #1	NARCO DME-195	80.	Bottom
5	ATCRBS	Wilcox 814 B	166.	Bottom
6	DME #2	King KN-63	206.	Bottom

[a]The Z-Distance is the distance from the nose of the aircraft, in inches.

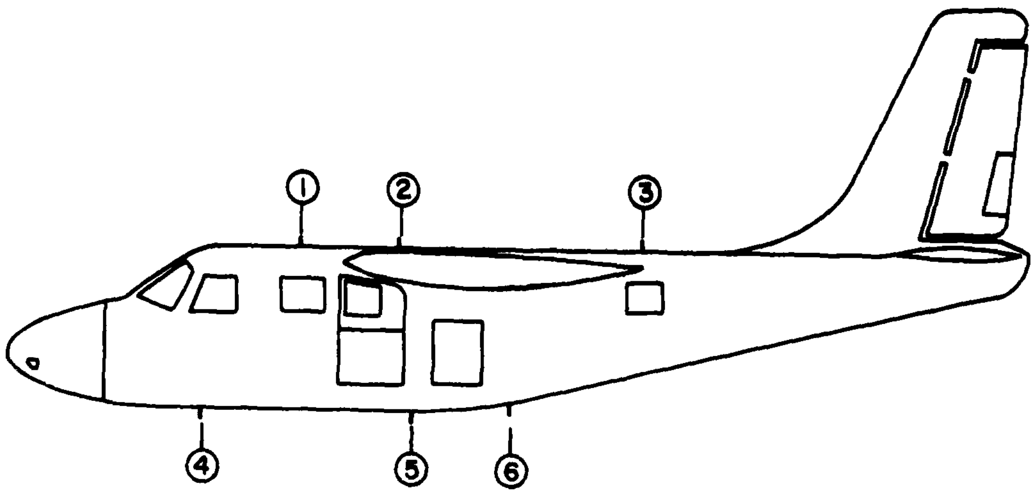

Figure B-1. Antenna locations, MIT LL configuration of the Aerocommander test aircraft.

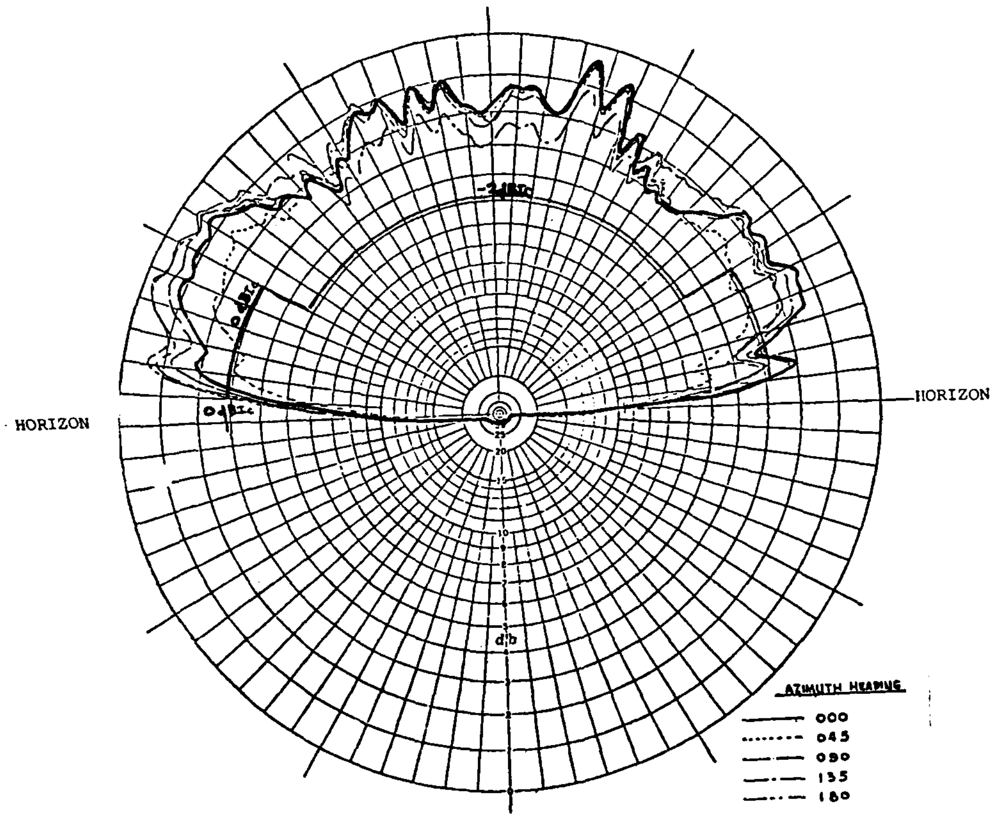

Figure B-2. GPS antenna pattern over 7' x 10' ground plane.

Figure B-3 is a sketch of the Aerocommander airframe showing front and side views. Since the Aerocommander airframe is noncylindrical, AVPAK, which models an airframe as a cylinder of finite length, was not used in determining the path loss between antennas. Instead, the procedure described in Reference 4 was used in determining the airframe path losses.

For each case, the peak and average on-tune, interfering-signal power levels that the transmitter may present to the GPS receiver were calculated. TABLE B-1 contains a summary of the calculations. None of the calculated levels exceeded the specified interference criteria, hence, the DME and ATCRBS systems aboard the MIT LL Aerocommander are not expected to interfere with the GPS operation.

OUT-OF-BAND TRANSMITTER ANALYSIS

Signal sources investigated in this analysis included two on-board VHF communication transmitters. The potential for interference was evaluated by comparing the possible harmonic/spurious power level each transmitter could present to the GPS receiver with an interference threshold. Received power levels were calculated at the L1 GPS frequency. A summary of the results is presented in TABLE B-2. The levels calculated for VHF #1 and VHF #2 were 17 dB and 21 dB, respectively, below the interference criterion. As a result, the VHF communication transmitters aboard the MIT LL Aerocommander are not expected to interfere with the GPS operation.

BURNOUT LIMITER ANALYSIS

The degradation criteria for the feedback limiting diode preceding the preamplifier are as follows. The diode can tolerate CW power of 5 watts and peak power of 300 watts. The maximum leakage power (saturation threshold) is 32 mW. A summary of the burnout/saturation calculations is presented in

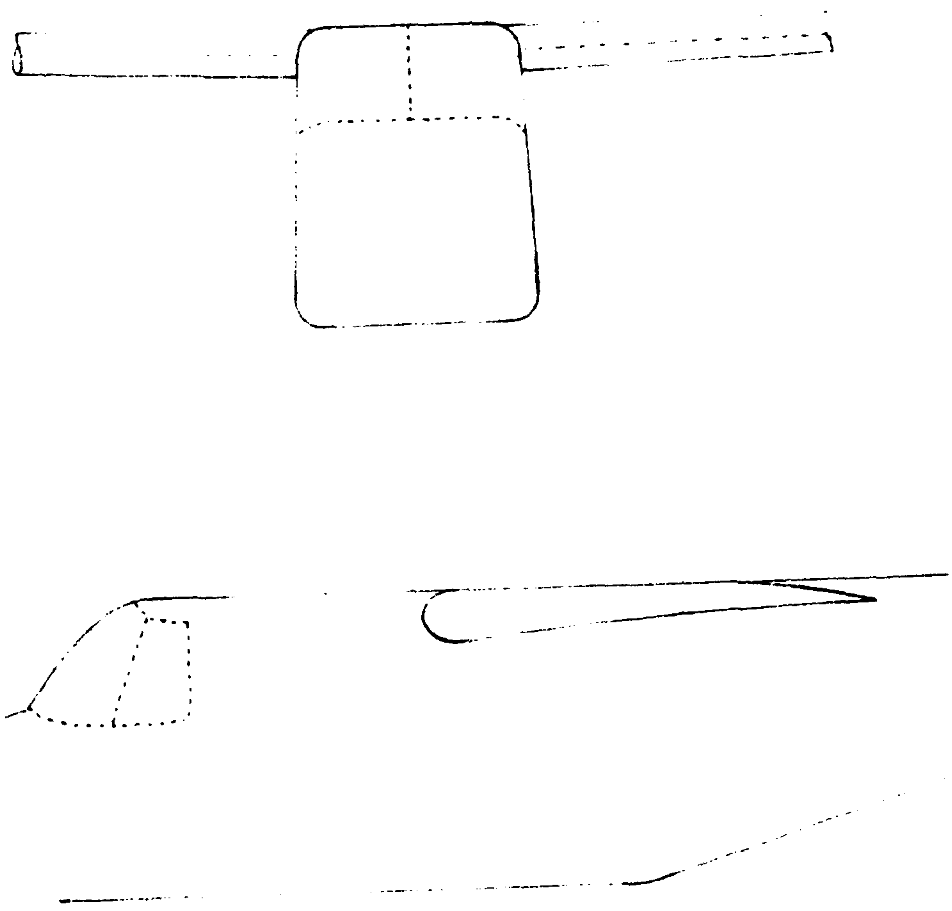

Figure B-3. Sketch of the Aerocommander.

TABLE B-1
SUMMARY OF THE CALCULATIONS FOR THE MIT LL AERO COMMANDER ADJACENT-SIGNAL ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	FDR (dB)	Path Loss (dB)	Peak Received Power (dBm)	Transmitter Duty Cycle (%)	Average Received Power (dBm)[b]
DME #1	GPS	50	0	-7	129	82	-168	0.105	-198
DME #2	GPS	60	0	-7	129	98	-174	0.105	-204
ATCRBS	GPS	57	0	-7	87	82	-119	1.35	-138

[a] Transmitter parameters are given in APPENDIX A.

[b] The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

TABLE B-2

SUMMARY OF THE CALCULATIONS FOR THE MIT LL AEROCOMMANDER OUT-OF-BAND ANALYSIS[a]

Transmitter ID	GPS ID	Tx Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Harmonic Attenuation (dB)	Path Loss (dB)	Received Power (dBm)[b]
VHF #1	GPS	38	0	-7	120	37	-126
VHF #2	GPS	44	0	-7	120	47	-130

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

TABLE B-3. Received power levels were calculated at the transmitted frequencies. A comparison of the burnout and saturation criteria with the calculated received power levels indicates that none of the transmitters aboard the MIT LL Aerocommander are expected to cause burnout or saturation of the GPS receiver.

SIMULTANEOUS OPERATION OF TRANSMITTERS

The GPS receiver will not experience burnout or saturation even if all transmitters on board the MIT LL Aerocommander operate simultaneously.

The total worst-case average effective on-tune power resulting from the simultaneous operation of all the on-board transmitters was calculated using Equation 5. P_m was determined to be below the GPS interference threshold level.

TABLE B-3
SUMMARY OF THE CALCULATIONS FOR THE MIT LL AEROCOMMANDER SATURATION/BURNOUT ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Path Loss (dB)	Antenna Mismatch (dB)	Peak Received Power (dBm)[b]	Tx Duty Duty Cycle (%)	Average Received Power (dBm)[c]
VHF #1	GPS	38	0	-7	15	31	-15	100	-15
VHF #2	GPS	44	0	-7	25	31	-19	100	-19
DME #1	GPS	50	0	-7	82	--	-39	0.105	-69
DME #2	GPS	60	0	-7	98	--	-45	0.105	-75
ATCRBS	GPS	57	0	-7	82	--	-32	1.35	-51

[a]Transmitter parameters are given in APPENDIX A.

[b]The peak received power may be compared with the saturation threshold (+15 dBm) and, for pulsed signals, with the peak burnout threshold (+55 dBm) of the feedback limiting diode.

[c]The average received power may be compared with the average burnout threshold (+37 dBm) of the feedback limiting diode.

APPENDIX C

GPS EMC ANALYSIS FOR THE FAA TECHNICAL CENTER BOEING 727

C-E SYSTEMS CONFIGURATION

The Boeing Model 727 is a short/medium range jet transport aircraft. The 727-100 version accommodates a maximum of 131 passengers. The aircraft uses a rear-engine layout with two engines mounted on the sides of the rear fuselage and a third at the base of the tail assembly. Figure C-1 shows the FAA Technical Center configuration of the Boeing 727. The antenna locations are shown in this figure and the equipment attached to each antenna is identified.

The C-E transmitter equipment complement of concern consists of two DME interrogators, one UHF transceiver, three VHF tranceivers, two HF transceivers, one Mode S transponder, and one ATCRBS transponder. In addition, the FAA Technical Center configuration will include two experimental Traffic Alert and Collision Avoidance Systems (TCAS). One TCAS will be provided by Lincoln Laboratory and the other TCAS will be provided by Dalmo Victor.

GPS INSTALLATION DESCRIPTION

The GPS system configuration on board the FAA Technical Center Boeing 727 consists of the prototype civil-use GPS receiver and three right-hand circularly polarized antennas. One GPS antenna is a Ball Micro-Strip Model AN-164B located on the top, center of the fuselage, approximately 870" (2210 cm) aft of the aircraft nose. The remaining two GPS antennas are located on the top, center of the air intake to the rear engine. These antennas, a Microwave Specialty Corporation Model 1133 and a Chu Associates Model CA-3207, are located approximately 1137" (2888 cm) and 1167" (2964 cm), respectively, aft of the aircraft nose. Figure C-2 shows the gain versus elevation angle characteristic of the Chu Associates antenna on a large aircraft. This

No.	ID	Equipment Type	Z-Distance[a]	Top/Bottom[b]
1	MODE S	Bendix TRU-2	240.	Top (Div.)
2	TCAS LL	Lincoln Labs	260.	Top (Div.)
3	TCAS DV	Dalmo Victor	300.	Top (Div.)
4	VHF #1	Bendix RTA-42A	500.	Top
5	GPS #1	Prototype	870.	Top
6	GPS #2	Prototype	1137.	Top
7	GPS #3	Prototype	1167.	Top
8	HF	Collins 618-T-2	1650.	Top
9	UHF/VHF #3	Collins ARC-159/ Bendix RTA-42A	280.	Bottom
10	TCAS DV	Dalmo Victor	340.	Bottom (Div.)
11	ATCRBS	Collins 621A-6	360.	Bottom
12	TCAS LL	Lincoln Labs	380.	Bottom (Div.)
13	MODE S	Bendix TRU-2	420.	Bottom (Div.)
14	VHF #2	Bendix RTA-42A	540.	Bottom
15	TACAN/DME #1	Sierra SRU 7000D	615. R.S.	Bottom
16	TACAN/DME #2	Sierra SRU 7000D	615. L.S.	Bottom

[a]The Z-Distance is the distance from the nose of the aircraft, in inches.

[b]Some systems on the FAA Technical Center Boeing 727 operate in the diversity (DIV.) mode. This means that the signal may be transmitted or received on either the antenna on the top of the aircraft or the antenna on the bottom of the aircraft.

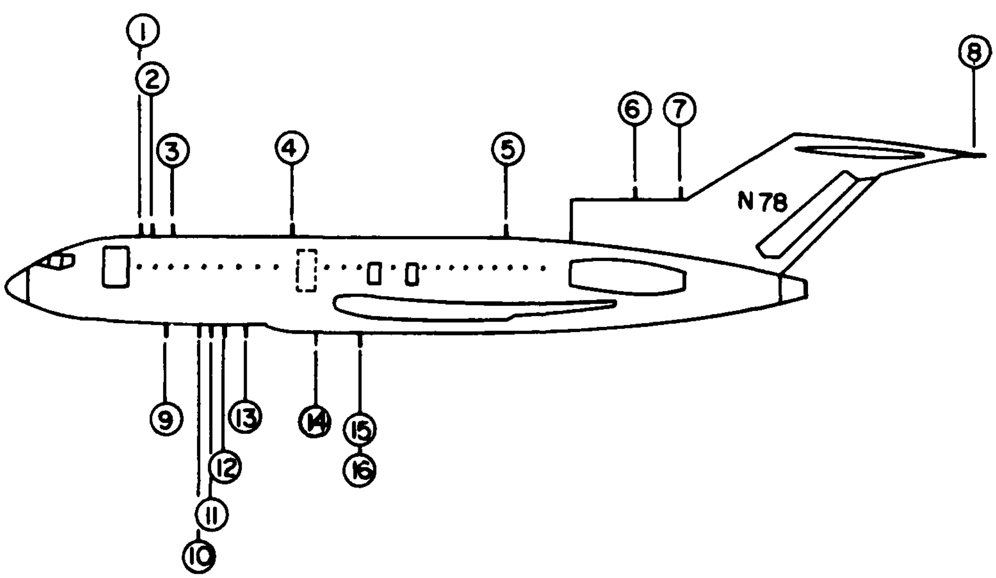

Figure C-1. Antenna locations, FAA Technical Center configuration of the Boeing 727 test aircraft.

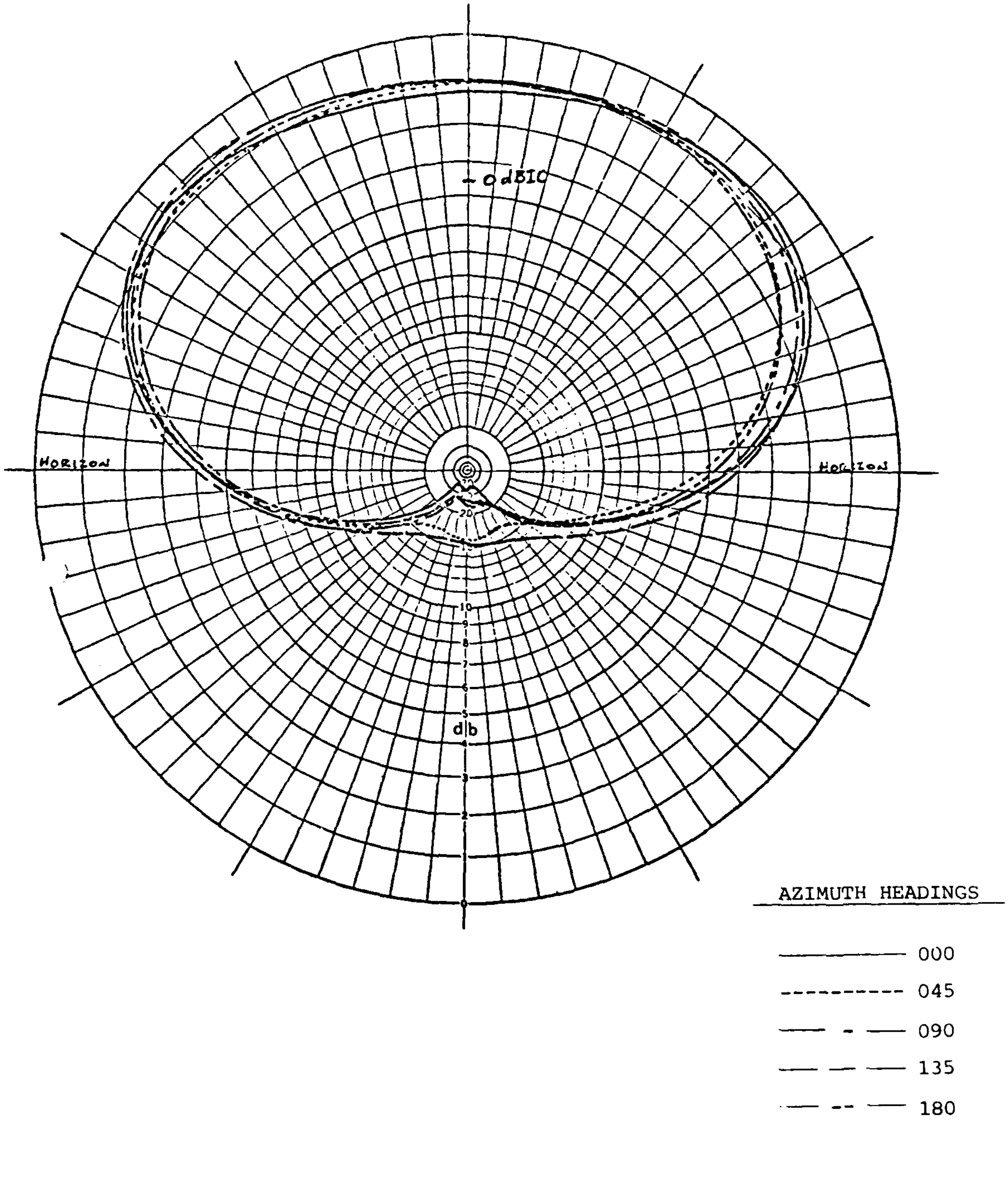

Figure C-2. GPS antenna pattern for typical installation on large cargo aircraft.

pattern was used to represent the GPS #1 antenna mounted on the Boeing 727 fuselage. The pattern of Figure B-2 was used to represent the GPS #2 and GPS #3 antennas mounted on the air intake structure of the Boeing 727, since the dimensions of the air intake more closely approximate the measurement conditions involved in obtaining the pattern of Figure B-2 than those for Figure C-2.

ADJACENT-SIGNAL ANALYSIS

The adjacent-signal analysis conducted for the FAA Technical Center configuration of the Boeing 727 focused attention on possible interference to GPS operation due to on-board DME, ATCRBS, Mode S, and TCAS emissions. The TCAS and the Mode S equipment operate in the diversity mode (i.e., the signal may be transmitted or received on either the antenna on the top of the aircraft, or the antenna on the bottom of the aircraft). The two DME antennas and the ATCRBS antenna are all located on the bottom of the aircraft fuselage.

AVPAK was used to determine the path loss between transmit antennas and GPS #1 (antenna #5 in Figure C-1). However, because of the irregular geometry of the propagation paths between the transmit antennas and GPS #2 and GPS #3 (antennas #6 and #7, respectively), the procedure described in Reference 4 was used instead of AVPAK to determine the airframe path loss values for these interactions.

For each case, the peak and average on-tune, interfering-signal power levels that the transmitter may present to the GPS receiver were calculated. TABLE C-1 contains a summary of the calculations. The table shows that the DME, ATCRBS, Mode S, and TCAS systems aboard the FAA Technical Center Boeing 727 are not expected to interfere with the GPS operation since the calculated average interfering-signal power level at the GPS receiver due to each of these sources is below the interference criteria.

TABLE C-1
SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER
BOEING 727 ADJACENT-SIGNAL ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	FDR (dB)	Path Loss (dB)	Peak Received Power (dBm)	Transmitter Duty Cycle (%)	Average Received Power (dBm)[b]
TACAN/DME #1	GPS #1	60	0	0	129	97	-166	0.10	-196
TACAN/DME #1	GPS #2	60	0	-7	129	90	-166	0.10	-196
TACAN/DME #1	GPS #3	60	0	-7	129	90	-166	0.10	-196
TACAN/DME #2	GPS #1	60	0	0	129	97	-166	0.10	-196
TACAN/DME #2	GPS #2	60	0	-7	129	90	-166	0.10	-196
TACAN/DME #2	GPS #3	60	0	-7	129	90	-166	0.10	-196
ATCRBS	GPS #1	57	0	0	96	98	-137	1.35[c]	-156
ATCRBS	GPS #2	57	0	-7	96	84	-130	1.35[c]	-149
ATCRBS	GPS #3	57	0	-7	96	84	-130	1.35[c]	-149
Mode S (T)	GPS #1	57	0	0	96	57	- 96	1.0[c]	-116
Mode S (T)	GPS #2	57	0	-7	96	66	-112	1.0[c]	-132
Mode S (T)	GPS #3	57	0	-7	96	67	-113	1.0[c]	-133
Mode S (B)	GPS #1	57	0	0	96	98	-137	1.0[c]	-157
Mode S (B)	GPS #2	57	0	-7	96	84	-130	1.0[c]	-150
Mode S (B)	GPS #3	57	0	-7	96	84	-130	1.0[c]	-150
TCAS LL (T)	GPS #1	57	0	0	83	56	-82	0.1[c]	-112
TCAS LL (T)	GPS #2	57	0	-7	83	65	-98	0.1[c]	-128
TCAS LL (T)	GPS #3	57	0	-7	83	65	-98	0.1[c]	-128
TCAS LL (B)	GPS #1	57	0	0	83	98	-124	0.1[c]	-154
TCAS LL (B)	GPS #2	57	0	-7	83	84	-110	0.1[c]	-140
TCAS LL (B)	GPS #3	57	0	-7	83	84	-110	0.1[c]	-140
TCAS DV (T)	GPS #1	57	0	0	83	56	-82	0.1[c]	-112
TCAS DV (T)	GPS #2	57	0	-7	83	65	-98	0.1[c]	-128
TCAS DV (T)	GPS #3	57	0	-7	83	65	-98	0.1[c]	-128
TCAS DV (B)	GPS #1	57	0	0	83	98	-124	0.1[c]	-154
TCAS DV (B)	GPS #2	57	0	-7	83	84	-110	0.1[c]	-140
TCAS DV (B)	GPS #3	57	0	-7	83	84	-110	0.1[c]	-140

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

[c]Duty cycle supplied by FAA.

OUT-OF-BAND TRANSMITTER ANALYSIS

The out-of-band transmitters investigated for potential interference to the GPS system aboard the FAA Technical Center Boeing 727 included one UHF transceiver, three VHF transceivers, and one HF transceiver. The potential for interference was evaluated by comparing the possible harmonic/spurious power level each transmitter could present to the GPS receiver with the interference criteria. Received power levels were calculated at the L1 GPS frequency. A summary of the results is presented in TABLE C-2. For all cases, the calculated maximum received power levels were below the interference threshold (-109 dBm). As a result, none of the out-of-band transmitters on board the Boeing 727 are expected to interfere with the GPS operation.

BURNOUT LIMITER ANALYSIS

Equation 4 from Section 2 was used to calculate the maximum peak received power from on-board transmitters for comparison with the GPS receiver peak burnout and saturation thresholds. Average received power, for comparison with the average burnout threshold, was calculated using Equation 2. A summary of the calculations is presented in TABLE C-3. A comparison of the burnout and saturation criteria with the calculated received power levels indicates that none of the transmitters aboard the aircraft are expected to cause burnout or saturation of the GPS receiver.

SIMULTANEOUS OPERATION OF TRANSMITTERS

The GPS receiver will not experience burnout or saturation even if all transceivers on board the FAA Technical Center Boeing 727 operate simultaneously.

The total worst-case average effective on-tune power resulting from the simultaneous operation of all on-board transmitters was calculated using Equation 5. P_m was determined to be below the GPS interference threshold.

TABLE C-2
SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER
BOEING 727 OUT-OF-BAND ANALYSIS[a]

Transmitter ID	GPS ID	Tx Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Harmonic Attenuation (dB)	Path Loss (dB)	Received Power (dBm)[b]
UHF	GPS #1	40	0	0	100	84	-144
UHF	GPS #2	40	0	-7	100	77	-144
UHF	GPS #3	40	0	-7	100	77	-144
VHF #1	GPS #1	44	0	0	120	56	-132
VHF #1	GPS #2	44	0	-7	120	61	-144
VHF #1	GPS #3	44	0	-7	120	62	-145
VHF #2	GPS #1	44	0	0	120	77	-153
VHF #2	GPS #2	44	0	-7	120	72	-155
VHF #2	GPS #3	44	0	-7	120	72	-155
VHF #3	GPS #1	44	0	0	120	77	-153
VHF #3	GPS #2	44	0	-7	120	72	-155
VHF #3	GPS #3	44	0	-7	120	72	-155
HF	GPS #1	56	0	0	120	62	-126
HF	GPS #2	56	0	-7	120	58	-129
HF	GPS #3	56	0	-7	120	58	-129

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

TABLE C-3
(Page 1 of 2)
SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER
BOEING 727 SATURATION/BURNOUT ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Path Loss (dB)	Antenna Mismatch (dB)	Peak Received Power (dBm)[b]	Transmitter Duty Cycle (%)	Average Received Power (dBm)[c]
DME #1	GPS #1	60	0	0	97	0	-37	0.10	-67
DME #1	GPS #2	60	0	-7	90	0	-37	0.10	-67
DME #1	GPS #3	60	0	-7	90	0	-37	0.10	-67
DME #2	GPS #1	60	0	0	95	0	-35	0.10	-65
DME #2	GPS #2	60	0	-7	90	0	-37	0.10	-67
DME #2	GPS #3	60	0	-7	90	0	-37	0.10	-67
UHF	GPS #1	40	0	0	70	14	-44	100.	-44
UHF	GPS #2	40	0	-7	63	14	-44	100.	-44
UHF	GPS #3	40	0	-7	63	14	-44	100.	-44
VHF #1	GPS #1	44	0	0	34	31	-21	100.	-21
VHF #1	GPS #2	44	0	-7	48	31	-42	100.	-42
VHF #1	GPS #3	44	0	-7	48	31	-42	100.	-42
VHF #2	GPS #1	44	0	0	55	31	-42	100.	-42
VHF #2	GPS #2	44	0	-7	78	31	-72	100.	-72
VHF #2	GPS #3	44	0	-7	78	31	-72	100.	-72
VHF #3	GPS #1	44	0	0	55	31	-42	100.	-42
VHF #3	GPS #2	44	0	-7	51	31	-45	100.	-45
VHF #3	GPS #3	44	0	-7	51	31	-45	100.	-45
HF	GPS #1	56	0	0	6[d]	60	-10	100.	-10
HF	GPS #2	56	0	-7	6[d]	60	-17	100.	-17
HF	GPS #3	56	0	-7	6[d]	60	-17	100.	-17

TABLE C-3

(Page 2 of 2)

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Path Loss (dB)	Antenna Mismatch (dB)	Peak Received Power (dBm)	Transmitter Duty Cycle[e] (%)	Average Received Power (dBm)
ATCRBS	GPS #1	57	0	0	98	0	-41	1.35	-60
ATCRBS	GPS #2	57	0	-7	84	0	-34	1.35	-53
ATCRBS	GPS #3	57	0	-7	84	0	-34	1.35	-53
Mode S (T)	GPS #1	57	0	0	57	0	0	1.0	-20
Mode S (T)	GPS #2	57	0	-7	66	0	-16	1.0	-36
Mode S (T)	GPS #3	57	0	-7	66	0	-16	1.0	-36
Mode S (B)	GPS #1	57	0	0	98	0	-41	1.0	-61
Mode S (B)	GPS #2	57	0	-7	84	0	-34	1.0	-54
Mode S (B)	GPS #3	57	0	-7	84	0	-34	1.0	-54
TCAS LL (T)	GPS #1	57	0	0	56	0	+ 1	0.1	-29
TCAS LL (T)	GPS #2	57	0	-7	65	0	-15	0.1	-45
TCAS LL (T)	GPS #3	57	0	-7	65	0	-15	0.1	-45
TCAS LL (B)	GPS #1	57	0	0	98	0	-41	0.1	-71
TCAS LL (B)	GPS #2	57	0	-7	84	0	-34	0.1	-64
TCAS LL (B)	GPS #3	57	0	-7	84	0	-34	0.1	-64
TCAS DV (T)	GPS #1	57	0	0	56	0	+ 1	0.1	-29
TCAS DV (T)	GPS #2	57	0	-7	65	0	-15	0.1	-45
TCAS DV (T)	GPS #3	57	0	-7	65	0	-15	0.1	-45
TCAS DV (B)	GPS #1	57	0	0	98	0	-41	0.1	-71
TCAS DV (B)	GPS #2	57	0	-7	84	0	-34	0.1	-64
TCAS DV (B)	GPS #3	57	0	-7	84	0	-34	0.1	-64

[a]Transmitter parameters are given in APPENDIX A.

[b]The peak received power may be compared with the saturation threshold (+15 dBm) and, for pulse signals, with the peak burnout threshold (+55 dBm) of the feedback limiting diode.

[c]The average received power may be compared with the average burnout threshold (+37 dBm) of the feedback limiting diode.

[d]Assumed minimum loss of 6-dB.

[e]Duty cycle supplied by FAA.

APPENDIX D

GPS EMC ANALYSIS FOR A TYPICAL BOEING 747

C-E SYSTEMS CONFIGURATION

The Boeing 747 is a very large commerical transport aircraft. The initial version can accommodate up to 490 passengers. The configuration of the Boeing 747 used in this analysis was obtained from FAA report #FAA-RD-77-6-LR.[8] The configuration was modified by omitting the Aerosat avionics and Collision Avoidance System included in Reference 8. This modification was made at the request of the FAA. Figure D-1 shows the antenna locations and identifies the equipment attached to each antenna on the Boeing 747.

The C-E transmitter equipment complement of concern consists of three VHF transceivers, two HF transceivers, two ATCRBS transponders, and two DME interrogators.

GPS INSTALLATION DESCRIPTION

The GPS configuration on board the Boeing 747 consists of the prototype civil-use GPS receiver and three right-hand circularly polarized antennas. The three GPS antennas are located on the top, center of the aircraft fuselage, at the locations shown in Reference 8 for the Aerosat L-Band antennas. The antenna pattern of Figure C-2 was used to represent the GPS antennas mounted on the Boeing 747.

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[8] Amis, C., An Intra-Aircraft EMC Analysis of Aerosat Avionics Versus Present And Future Avionics Systems, FAA-RD-77-6-LR, U.S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, DC, September 1975.

No.	ID	Equipment Type	Z-Distance[a]	Top/Bottom
1	VHF #1	Bendix RTA-42A	678.	Top
2	GPS #1	Prototype	944.	Top
3	VHF #3	Bendix RTA-41A	1292.	Top
4	GPS #2	Prototype	1497.	Top
5	GPS #3	Prototype	1928.	Top
6	ATCRBS #1	Collins 621A-6	449.	Bottom
7	ATCRBS #2	Bendix TRA-63A	489.	Bottom
8	DME #1	King KDM-7000	591.	Bottom
9	DME #2	Collins 860E-3	731.	Bottom
10	VHF #2	King KTR-9100	1175.	Bottom
11	HF #1	Collins 618T-2	1932.	Wing Tip
12	HF #2	Collins 618T-2B	1932.	Wing Tip

[a]The Z-Distance is the distance from the nose of the aircraft, in inches.

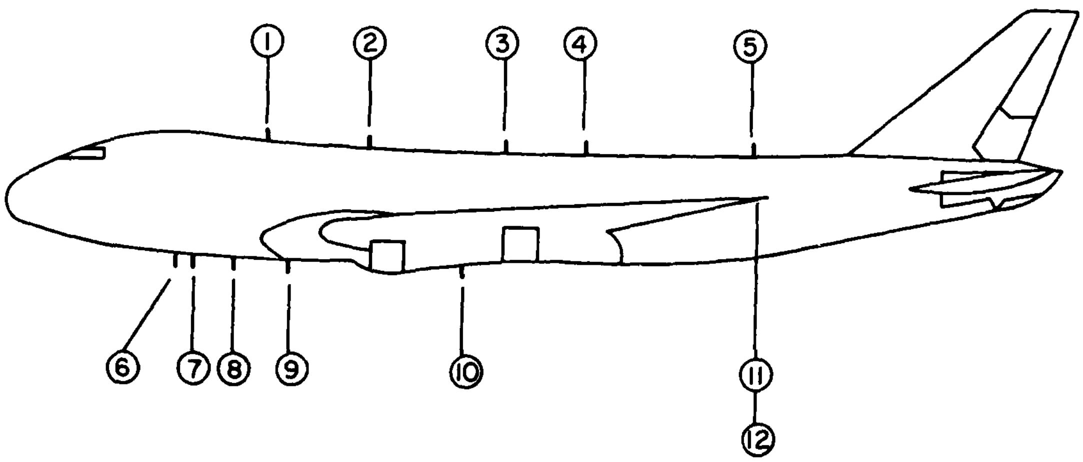

Figure D-1. Antenna locations, FAA-RD-77-6-LR configuration of the Boeing 747 aircraft.

ADJACENT-SIGNAL ANALYSIS

The adjacent-signal analysis conducted for the Boeing 747 focused attention on possible interference to GPS operation due to on-board DME and ATCRBS emissions. The DME and ATCRBS antennas are mounted on the bottom of the aircraft fuselage.

For each case, the peak and average on-tune, interfering-signal power levels that the transmitter may present to the GPS receiver were calculated. AVPAK was used to determine the path loss between the transmit and GPS receive antennas. TABLE D-1 contains a summary of the calculations. The table shows that the DME and ATCRBS systems aboard the Boeing 747 are not expected to interfere with the GPS operation since the calculated interfering-signal power level at the GPS receiver due to each of the sources is below the interference criteria.

OUT-OF-BAND TRANSMITTER ANALYSIS

The out-of-band transmitters investigated for potential interference to the GPS aboard the Boeing 747 included three VHF transceivers and two HF transceivers. The potential for interference was evaluated by comparing the possible harmonic/spurious power level each transmitter could present to the GPS receiver with the interference criteria. Received power levels were calculated at the L1 GPS frequency. A summary of the results is presented in TABLE D-2. For all interactions, the calculated maximum received power levels were below the interference threshold (-109 dBm). As a result, none of the out-of-band transmitters on board the Boeing 747 are expected to interfere with the GPS operation.

BURNOUT LIMITER ANALYSIS

The maximum peak received power from on-board transmitters was calculated, using Equation 4 of Section 2, for comparison with the GPS receiver saturation threshold (+15 dBm). Average received power, for comparison with the burnout

TABLE D-1
SUMMARY OF THE CALCULATIONS FOR THE BOEING 747
ADJACENT-SIGNAL ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	FDR (dB)	Path Loss (dB)	Peak Received Power (dBm)	Transmitter Duty Cycle (%)	Average Received Power (dBm)[b]
ATCRBS #1	GPS #1	57	0	0	97	116	-156	1.35	-175
ATCRBS #1	GPS #2	57	0	0	97	109	-149	1.35	-168
ATCRBS #1	GPS #3	57	0	0	97	106	-146	1.35	-165
ATCRBS #2	GPS #1	60	0	0	91	117	-148	1.35	-167
ATCRBS #2	GPS #2	60	0	0	91	109	-140	1.35	-159
ATCRBS #2	GPS #3	60	0	0	91	107	-138	1.35	-157
DME #1	GPS #1	60	0	0	129	119	-188	0.10	-218
DME #1	GPS #2	60	0	0	129	110	-179	0.10	-209
DME #1	GPS #3	60	0	0	129	107	-176	0.10	-206
DME #2	GPS #1	60	0	0	129	119	-188	0.10	-218
DME #2	GPS #2	60	0	0	129	110	-179	0.10	-209
DME #2	GPS #3	60	0	0	129	107	-176	0.10	-206

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

TABLE D-2
SUMMARY OF THE CALCULATIONS FOR THE
BOEING 747 OUT-OF-BAND ANALYSIS[a]

Transmitter ID	GPS ID	Tx Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Harmonic Attenuation (dB)	Path Loss (dB)	Received Power (dBm)[b]
VHF #1	GPS #1	44	0	0	120	50	-126
VHF #1	GPS #2	44	0	0	120	63	-139
VHF #1	GPS #3	44	0	0	120	66	-142
VHF #2	GPS #1	44	0	0	120	158	-234
VHF #2	GPS #2	44	0	0	120	177	-253
VHF #2	GPS #3	44	0	0	120	154	-230
VHF #3	GPS #1	45	0	0	120	55	-130
VHF #3	GPS #2	45	0	0	120	52	-127
VHF #3	GPS #3	45	0	0	120	64	-139
HF #1	GPS #1	56	0	0	120	73	-137
HF #1	GPS #2	56	0	0	120	72	-136
HF #1	GPS #3	56	0	0	120	72	-136
HF #2	GPS #1	56	0	0	120	73	-137
HF #2	GPS #2	56	0	0	120	72	-136
HF #2	GPS #3	56	0	0	120	72	-136

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

threshold (+37 dBm), was calculated using Equation 2. A summary of the calculations is presented in TABLE D-3. A comparison of the burnout and saturation criteria with the calculated received power levels indicates that none of the transmitters aboard the aircraft are expected to cause burnout or saturation of the GPS receiver.

SIMULTANEOUS OPERATION OF TRANSMITTERS

The GPS receiver will not experience burnout or saturation even if all transmitters on board the Boeing 747 operate simultaneously.

The total worst-case average effective on-tune power resulting from the simultaneous operation of all on-board transmitters was calculated using Equation 5. P_m was determined to be below the GPS interference threshold level.

TABLE D-3
SUMMARY OF THE CALCULATIONS FOR THE BOEING 747
SATURATION/BURNOUT ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Path Loss (dB)	Antenna Mismatch (dB)	Peak Received Power (dBm)[b]	Transmitter Duty Cycle (%)	Average Received Power (dBm)[c]
VHF #1	GPS #1	44	0	0	31	31	-18	100.	-18
VHF #1	GPS #2	44	0	0	42	31	-29	100.	-29
VHF #1	GPS #3	44	0	0	45	31	-32	100.	-32
VHF #2	GPS #1	44	0	0	63	31	-50	100.	-50
VHF #2	GPS #2	44	0	0	63	31	-50	100.	-50
VHF #2	GPS #3	44	0	0	62	31	-49	100.	-49
VHF #3	GPS #1	45	0	0	34	31	-20	100.	-20
VHF #3	GPS #2	45	0	0	31	31	-17	100.	-17
VHF #3	GPS #3	45	0	0	39	31	-25	100.	-25
HF #1	GPS #1	56	0	0	6[d]	60	-10	100.	-10
HF #1	GPS #2	56	0	0	6[d]	60	-10	100.	-10
HF #1	GPS #3	56	0	0	6[d]	60	-10	100.	-10
HF #2	GPS #1	56	0	0	6[d]	60	-10	100.	-10
HF #2	GPS #2	56	0	0	6[d]	60	-10	100.	-10
HF #2	GPS #3	56	0	0	6[d]	60	-10	100.	-10
ATCRBS #1	GPS #1	57	0	0	116	0	-59	1.35	-78
ATCRBS #1	GPS #2	57	0	0	109	0	-52	1.35	-71
ATCRBS #1	GPS #3	57	0	0	106	0	-49	1.35	-68
ATCRBS #2	GPS #1	60	0	0	117	0	-57	1.35	-76
ATCRBS #2	GPS #2	60	0	0	109	0	-49	1.35	-68
ATCRBS #2	GPS #3	60	0	0	107	0	-47	1.35	-66
DME #1	GPS #1	60	0	0	119	0	-59	0.10	-89
DME #1	GPS #2	60	0	0	110	0	-50	0.10	-80
DME #1	GPS #3	60	0	0	107	0	-47	0.10	-77
DME #2	GPS #1	60	0	0	119	0	-59	0.10	-89
DME #2	GPS #2	60	0	0	110	0	-50	0.10	-80
DME #2	GPS #3	60	0	0	107	0	-47	0.10	-77

[a] Transmitter parameters are given in APPENDIX A.

[b] The peak received power may be compared with the saturation threshold (+15 dBm) and, for pulsed signals, with the peak burnout threshold (+55 dBm) of the feedback limiting diode.

[c] The average received power may be compared with the average burnout threshold (+37 dBm) of the feedback limiting diode.

[d] Assumed minimum loss of 6-dB.

APPENDIX E

GPS EMC ANALYSIS OF THE FAA TECHNICAL CENTER AEROCOMMANDER

C-E SYSTEMS CONFIGURATION

Figure E-1 shows the FAA Technical Center configuration of the Aerocommander. This configuration was described in a letter[9] dated October 29, 1981, and confirmed in a telephone conversation[10] in November, 1981. Figure E-1 shows the antenna locations and identifies the equipment attached to each antenna. The C-E transmitter complement of concern consists of two VHF transceivers, two DME interrogators, and one Mode S transponder.

GPS INSTALLATION DESCRIPTION

The GPS system configuration on board the FAA Technical Center Aerocommander consists of the prototype civil-use GPS receiver and two right-hand circularly polarized antennas. Both GPS antennas are mounted on the top of the aircraft fuselage. One antenna is located over the rear of the aircraft wings while the other antenna is located aft of the wings. Figure B-2 shows the gain versus elevation angle characteristic used to represent the GPS antennas for this analysis.

ADJACENT-SIGNAL ANALYSIS

The adjacent-signal analysis conducted for the FAA Technical Center configuration of the Aerocommander focused attention on possible interference to GPS operation due to on-board DME and Mode S transmissions. The two DME

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[9] Memorandum from Edward Sawtelle, Technical Program Manager, NAVSTAR/GPS, FAA Technical Center, Atlantic City, NJ to William Reytar, ARD-452C, FAA Spectrum Management Branch, Washington, DC, subject: Antennas/Transmitter Power on N-50, 29 October 1981.

[10] TELCON from R. Mullen, ECAC, to George Paolacci, FAA Technical Center, Atlantic City, NJ, 5 November 1981.

No.	ID	Equipment Type	Z-Distance[a]	Top/Bottom
1	Mode S	Mode S Transponder	95.	Top
2	VHF #1	Collins VHF-20	105.	Top
3	GPS #1	Prototype	238.	Top
4	GPS #2	Prototype	266.	Top
5	VHF #2	Collins VHF-20	276.	Top
6	DME #1	King KN-65	84.	Bottom
7	DME #2	King KN-65	166.	Bottom

[a]The Z-Distance is the distance from the nose of the aircraft, in inches.

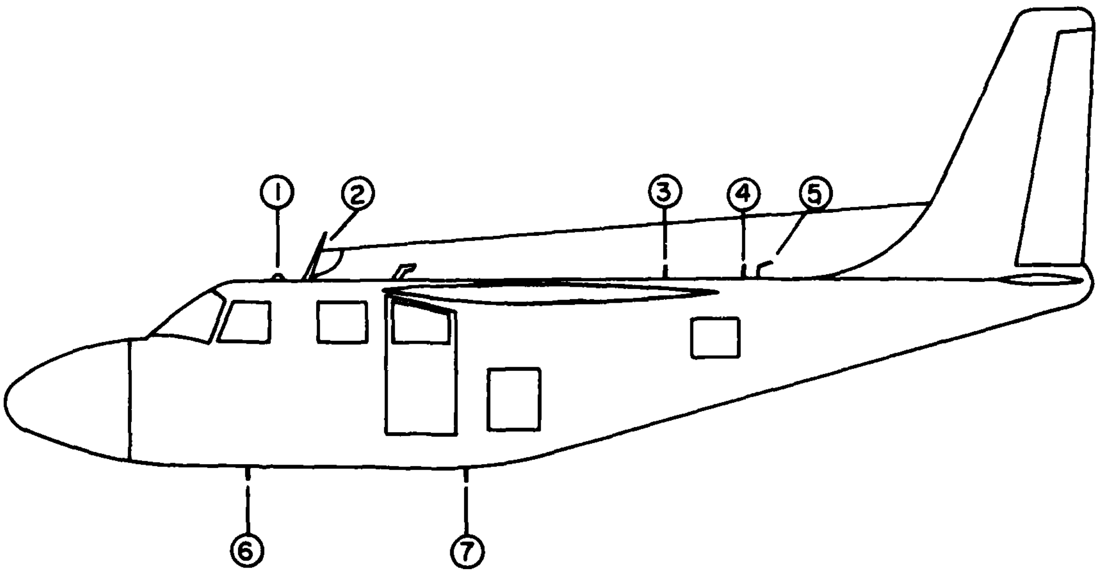

Figure E-1. Antenna locations, FAA Technical Center configuration of the Aerocommander test aircraft.

antennas are located on the bottom of the aircraft fuselage while the Mode S antenna is located on the top of the aircraft fuselage.

For each interaction, the peak and average on-tune, interfering-signal power levels that the transmitter may present to the GPS receiver were calculated using Equation 1. The airframe path losses were determined using the procedure described in Reference 4. The frequency-dependent rejection, described in APPENDIX F, was calculated using the bounds on the transmitter emission spectrum, the GPS receiver selectivity and the minimum frequency separation. Equation 2 was used to calculate the average effective on-tune interference power level at the input to the GPS receiver. The average interfering-signal power was then compared with the GPS interference thresholds (-109 dBm for C/A signal acquisition and -106 dBm for C/A signal code and carrier tracking). TABLE E-1 contains a summary of the calculations. None of the calculated levels exceeded the specified interference criteria; therefore, the DME and Mode S systems aboard the FAA Technical Center Aerocommander are not expected to interfere with the GPS operation.

OUT-OF-BAND TRANSMITTER ANALYSIS

Signal sources investigated in this analysis included two on-board VHF communication transmitters. The potential for interference was evaluated by comparing the possible harmonic/spurious power level each transmitter could present to the GPS receiver with the interference criteria. Received power levels were calculated at the L1 GPS frequency (1575.42 MHz). A summary of the results is presented in TABLE E-2. None of the calculated levels exceed the interference criteria (-109 dBm and -106 dBm), hence the VHF communication transmitters aboard the FAA Technical Center Aerocommmander are not expected to interfere with the GPS operation. It should be noted, however, that the interaction between VHF #2 and GPS #2 (separated by only 10" (25.4 cm) on the aircraft fuselage) results in an interfering signal level that is equal to the interference threshold for C/A signal acquisition (-109 dBm). The VHF #2 signal will use up the GPS jamming-to-signal (J/S) margin and may make it vulnerable to interference from other sources.

TABLE E-1
SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER AEROCOMMANDER ADJACENT-SIGNAL ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	FDR (dB)	Path Loss (dB)	Peak Received Power (dBm)	Transmitter Duty Cycle (%)	Average Received Power (dBm)[b]
Mode S	GPS #1	55	0	-7	96	44	-92	1.0	-112
Mode S	GPS #2	55	0	-7	96	46	-94	1.0	-114
DME #1	GPS #1	50	0	-7	129	93	-179	0.105	-209
DME #1	GPS #2	50	0	-7	129	84	-170	0.105	-200
DME #2	GPS #1	50	0	-7	129	93	-179	0.105	-209
DME #2	GPS #2	50	0	-7	129	80	-166	0.105	-196

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

TABLE E-2

SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER AEROCOMMANDER OUT-OF-BAND ANALYSIS[a]

Transmitter ID	GPS ID	Tx Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Harmonic Attenuation (dB)	Path Loss (dB)	Received Power (dBm)[b]
VHF #1	GPS #1	43	0	-7	120	47	-131
VHF #1	GPS #2	43	0	-7	120	49	-133
VHF #2	GPS #1	43	0	-7	120	36	-120
VHF #2	GPS #2	43	0	-7	120	25	-109

[a]Transmitter parameters are given in APPENDIX A.

[b]The average received power level may be directly compared with the GPS interference thresholds for C/A signal acquisition (-109 dBm) and C/A signal code and carrier tracking (-106 dBm).

BURNOUT LIMITER ANALYSIS

The feedback limiting diode can tolerate CW power of 5 watts and peak power of 300 watts. The maximum leakage power (saturation threshold) is +15 dBm. A summary of the burnout/saturation calculations is presented in TABLE E-3. Received power levels were calculated at the transmitted frequencies. A comparison of the burnout and saturation criteria with the calculated received power levels indicates that none of the transmitters aboard the FAA Technical Center Aerocommander are expected to cause burnout or saturation of the GPS receiver.

SIMULTANEOUS OPERATION OF TRANSMITTERS

The GPS receiver will not experience burnout or saturation even if all transmitters on board the FAA Technical Center Aerocommander operate simultaneously.

Using Equation 5, the worst-case average effective on-tune power, referenced to the GPS #2 receiver input, resulting from the simultaneous operation of the VHF #2 transceiver and the Mode S interrogator was calculated to be -108 dBm. As a result, the simultaneous operation of these systems may prevent the GPS #2 receiver from acquiring the signal from satellites until the elevation angle has increased to more than 5° above the horizon. The total average effective on-tune power resulting from the simultaneous operation of all other on-board transmitters was determined to be below the GPS interference threshold level.

TABLE E-3

SUMMARY OF THE CALCULATIONS FOR THE FAA TECHNICAL CENTER AEROCOMMANDER SATURATION/BURNOUT ANALYSIS[a]

Transmitter ID	GPS ID	Tx Peak Output Power (dBm)	Tx Antenna Gain (dBi)	GPS Antenna Gain (dBi)	Path Loss (dB)	Antenna Mismatch (dB)	Peak Received Power (dBm)[b]	Tx Duty Cycle (%)	Average Received Power (dBm)[c]
VHF #1	GPS #1	43	0	-7	26	31	-21	100.	-21
VHF #1	GPS #2	43	0	-7	28	31	-23	100.	-23
VHF #2	GPS #1	43	0	-7	16	31	-11	100.	-11
VHF #2	GPS #2	43	0	-7	4	31	+ 1	100.	+ 1
Mode S	GPS #1	55	0	-7	44	0	+ 4	1.0	-16
Mode S	GPS #2	55	0	-7	46	0	+ 2	1.0	-18
DME #1	GPS #1	50	0	-7	93	0	-50	0.105	-80
DME #1	GPS #2	50	0	-7	84	0	-41	0.105	-71
DME #2	GPS #1	50	0	-7	93	0	-50	0.105	-80
DME #2	GPS #2	50	0	-7	80	0	-37	0.105	-67

[a]Transmitter parameters are given in APPENDIX A.

[b]The peak received power may be compared with the saturation threshold (+15 dBm) and, for pulsed signals with the peak burnout threshold (+55 dBm) of the feedback limiting diode.

[c]The average received power may be compared with the average burnout threshold (+37 dBm) of the feedback limiting diode.

APPENDIX F

FREQUENCY-DEPENDENT REJECTION (FDR)

It is often useful to evaluate the impact of an undesired radiating source on a potential victim receiver in terms of the power level, referred to the receiver input port, of an equivalent on-tune CW source (i.e., the input power level of an on-tune CW source that would result in the same average power, measured at the detector input, as would the potential interfering transmission). This equivalent input power can then be compared to the receiver interference threshold to evaluate the potential of interference due to that source.

The calculation of the equivalent on-tune power level is facilitated by the evaluation of a term, frequency-dependent rejection (FDR), that accounts for the fact that not all of the energy incident on the receiver input port is accepted by the potential victim receiver. FDR may be further subdivided into two terms, off-frequency rejection (OFR) and on-tune rejection (OTR). The first accounts for the loss of energy due to any detuning of the potential interfering transmitter from the potential victim receiver. The second accounts for the fact that the emission spectrum of the transmitter may be substantially broader than the receiver bandwidth so that, even if receiver and transmitter are cotuned, only a fraction of the incident energy will be accepted. The definitions for FDR, OTR, and OFR are as follows.

FDR depends on the detuning, and is the rejection provided by a receiver to a transmitted signal as a result of both the limited bandwidth of the receiver with respect to the emission spectrum and the specified detuning.

OTR is the rejection provided by a receiver selectivity characteristic to a cotuned transmitter as a result of an emission spectrum exceeding the receiver bandwidth.

OFR is the rejection, over and above the OTR, provided by specified detuning of the receiver with respect to the transmitter.

Precise mathematical definitions for FDR, OTR, and OFR are as follows.

Frequency-dependent rejection, in dB:

$$\mathrm{FDR}(\Delta f) \overset{\text{def}}{=} 10 \log_{10} \frac{\int_0^{\infty} S(f)df}{\int_0^{\infty} S(f)R(f+\Delta f)df} \qquad \text{(F-1)}$$

where

$S(f)$ = transmitter power spectral density, in watts/Hz

$R(f)$ = receiver selectivity with the receiver tuned to frequency, f

Δf = difference beween transmitter and receiver tuned frequencies, in Hz.

On-tune rejection, in dB:

$$\mathrm{OTR} = 10 \log_{10} \frac{\int_0^{\infty} S(f)df}{\int_0^{\infty} S(f)R(f)df} \qquad \text{(F-2)}$$

Off-frequency rejection, in dB:

$$\mathrm{OFR}(\Delta f) = 10 \log_{10} \frac{\int_0^{\infty} S(f)R(f)df}{\int_0^{\infty} S(f)R(f+\Delta f)df} \qquad \text{(F-3)}$$

Frequency-dependent rejection, in dB:

$$\mathrm{FDR}(\Delta f) = \mathrm{OFR}(\Delta f) + \mathrm{OTR} \qquad \text{(F-4)}$$

An example using the DME interrogator and the GPS receiver preamplifier will illustrate how OFR, OTR, and FDR are determined. The upper boundary of the DME interrogator power spectral density was calculated from the DME interrogator pulse parameters using a method developed by Mason and Zimmermann.[9] Figure F-1 shows the normalized power spectral density boundary of the DME interrogator. The selectivity of the prototype civil-use GPS receiver preamplifier was given in Reference 2 and is shown in Figure F-2. Equation F-2 was used to calculate the OTR. Equation F-3 was used to calculate the OFR as a function of the separation between the transmitter and receiver tuned frequencies. The OFR and OTR values are combined using Equation F-3 to obtain the frequency-dependent rejection provided by the preamplifier to the DME interrogation signal. Figure F-3 shows a print-out from an ECAC computer program which calculates OTR, OFR, and FDR. The FDR curve is plotted in Figure F-4.

The DME interrogator transmits on frequencies between 1025 and 1150 MHz, hence the minimum frequency separation between the transmitter and the receiver tuned frequencies is 425 MHz. Then, from either Figure F-3 or Figure F-4, the minimum value of FDR is found to be approximately 67.7 dB.

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[9]Mason, S., Zimmermann, H., Electronic Circuits, Signals, and Systems, John Wiley & Sons, Inc., New York, N.Y. pp 237-242; 1960.

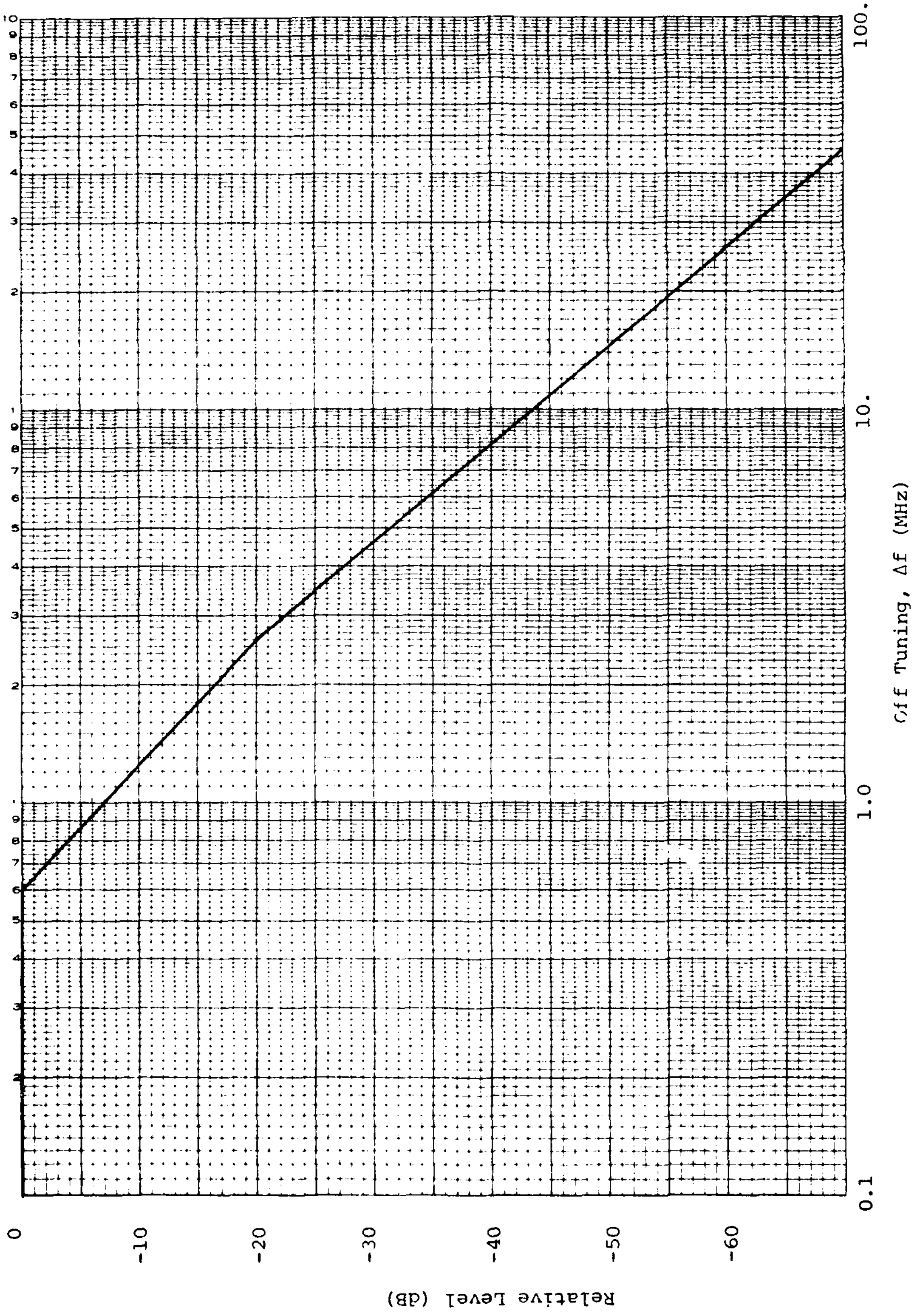

Figure F-1. Normalized power spectral density boundary of the DME interrogator.

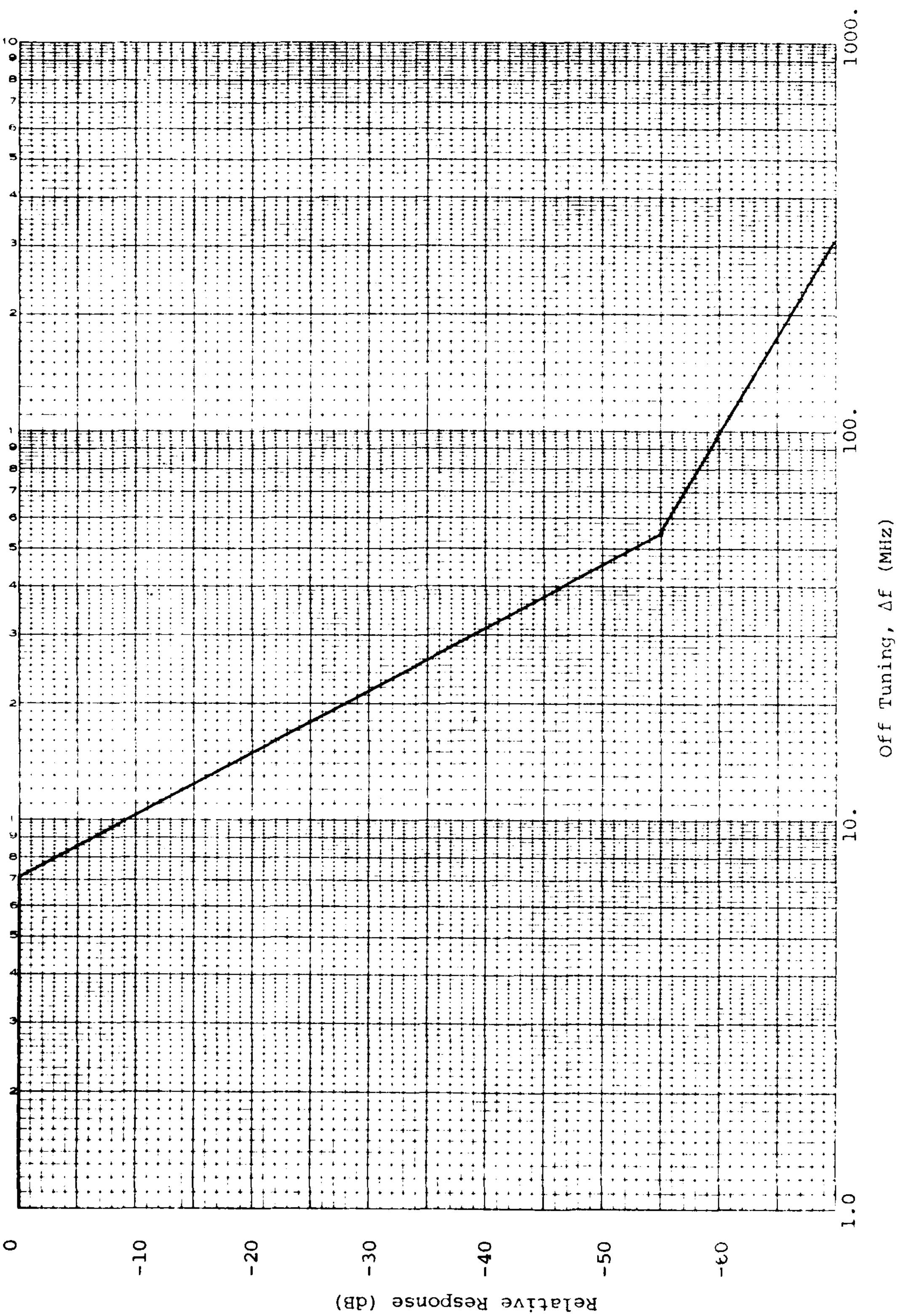

Figure F-2. GPS preamplifier selectivity.

TRANSMITTER :	DME INTERROGATOR	RECEIVER :	PREAMPLIFIER FILTER
TRANSMITTER ID NUMBER :	1	RECEIVER ID NUMBER :	1
TRANSMITTER 3-DB BANDWIDTH :	150. KHZ	RECEIVER 3-DB BANDWIDTH :	1.600+04 KHZ
EMISSION CURVE LEFT EXTRAP SLOPE :	-40. DB/DECADE	SELECTIVITY CURVE LEFT EXTRAP SLOPE :	20. DB/DECADE
EMISSION CURVE RIGHT EXTRAP SLOPE :	-40. DB/DECADE	SELECTIVITY CURVE RIGHT EXTRAP SLOPE :	20. DB/DECADE
NUMBER OF EMISSION CURVE POINTS :	7	NUMBER OF SELECTIVITY CURVE POINTS :	5
PULSED OUTPUT POWER :	YES		

EMISSION CURVE : (KHZ)	(DB)	SELECTIVITY CURVE : (KHZ)	(DB)
-2600.000	-60.0	-55000.000	50.0
-260.000	-20.0	-8000.000	3.0
-75.000	-3.0	.000	.0
.000	.0	8000.000	3.0
75.000	-3.0	55000.000	50.0
260.000	-20.0		
2600.000	-60.0		

FILE NAME :	FDRPLT
FILE SECURITY CLASSIFICATION :	U
FILE WRITE KEY :	NELLUM
STARTING SECTOR :	261

ON TUNE REJECTION : .0 DB

OTR, OFR & FDR BASED ON PEAK SIGNAL POWER

DELTA F (KHZ)	OFR (DB)	FDR (DB)	DELTA F (KHZ)	OFR (DB)	FDR (DB)
1.0000+05	55.2	55.2	3.1623+05	65.2	65.2
1.0233+05	55.4	55.4	3.2359+05	65.4	65.4
1.0471+05	55.6	55.6	3.3113+05	65.6	65.6
1.0715+05	55.8	55.8	3.3884+05	65.8	65.8
1.0965+05	56.0	56.0	3.4674+05	66.0	66.0
1.1220+05	56.2	56.2	3.5481+05	66.2	66.2
1.1482+05	56.4	56.4	3.6308+05	66.4	66.4
1.1749+05	56.6	56.6	3.7154+05	66.6	66.6
1.2023+05	56.8	56.8	3.8019+05	66.8	66.8
1.2303+05	57.0	57.0	3.8905+05	67.0	67.0
1.2589+05	57.2	57.2	3.9811+05	67.2	67.2
1.2882+05	57.4	57.4	4.0738+05	67.4	67.4
1.3183+05	57.6	57.6	4.1687+05	67.6	67.6
1.3490+05	57.8	57.8	4.2658+05	67.8	67.8
1.3804+05	58.0	58.0	4.3652+05	68.0	68.0
1.4125+05	58.2	58.2	4.4668+05	68.2	68.2
1.4454+05	58.4	58.4	4.5709+05	68.4	68.4
1.4791+05	58.6	58.6	4.6774+05	68.6	68.6
1.5136+05	58.8	58.8	4.7863+05	68.8	68.8
1.5488+05	59.0	59.0	4.8978+05	69.0	69.0
1.5849+05	59.2	59.2	5.0119+05	69.2	69.2
1.6218+05	59.4	59.4	5.1286+05	69.4	69.4
1.6596+05	59.6	59.6	5.2481+05	69.6	69.6
1.6982+05	59.8	59.8	5.3703+05	69.8	69.8
1.7378+05	60.0	60.0	5.4954+05	70.0	70.0
1.7783+05	60.2	60.2	5.6234+05	70.2	70.2
1.8197+05	60.4	60.4	5.7544+05	70.4	70.4
1.8621+05	60.6	60.6	5.8884+05	70.6	70.6
1.9055+05	60.8	60.8	6.0256+05	70.8	70.8
1.9498+05	61.0	61.0	6.1659+05	71.0	71.0
1.9953+05	61.2	61.2	6.3096+05	71.2	71.2
2.0417+05	61.4	61.4	6.4565+05	71.4	71.4
2.0893+05	61.6	61.6	6.6069+05	71.6	71.6
2.1380+05	61.8	61.8	6.7608+05	71.8	71.8
2.1878+05	62.0	62.0	6.9183+05	72.0	72.0
2.2387+05	62.2	62.2	7.0795+05	72.2	72.2
2.2909+05	62.4	62.4	7.2444+05	72.4	72.4
2.3442+05	62.6	62.6	7.4131+05	72.6	72.6
2.3988+05	62.8	62.8	7.5858+05	72.8	72.8
2.4547+05	63.0	63.0	7.7625+05	73.0	73.0
2.5119+05	63.2	63.2	7.9433+05	73.2	73.2
2.5704+05	63.4	63.4	8.1283+05	73.4	73.4
2.6303+05	63.6	63.6	8.3176+05	73.6	73.6
2.6915+05	63.8	63.8	8.5114+05	73.8	73.8
2.7542+05	64.0	64.0	8.7096+05	74.0	74.0
2.8184+05	64.2	64.2	8.9125+05	74.2	74.2
2.8840+05	64.4	64.4	9.1201+05	74.4	74.4
2.9512+05	64.6	64.6	9.3325+05	74.6	74.6
3.0200+05	64.8	64.8	9.5499+05	74.8	74.8
3.0903+05	65.0	65.0	9.7724+05	75.0	75.0

Figure F-3. Computer print-out of OTR, OFR, and FDR for the combination of the DME interrogator and the GPS preamplifier.

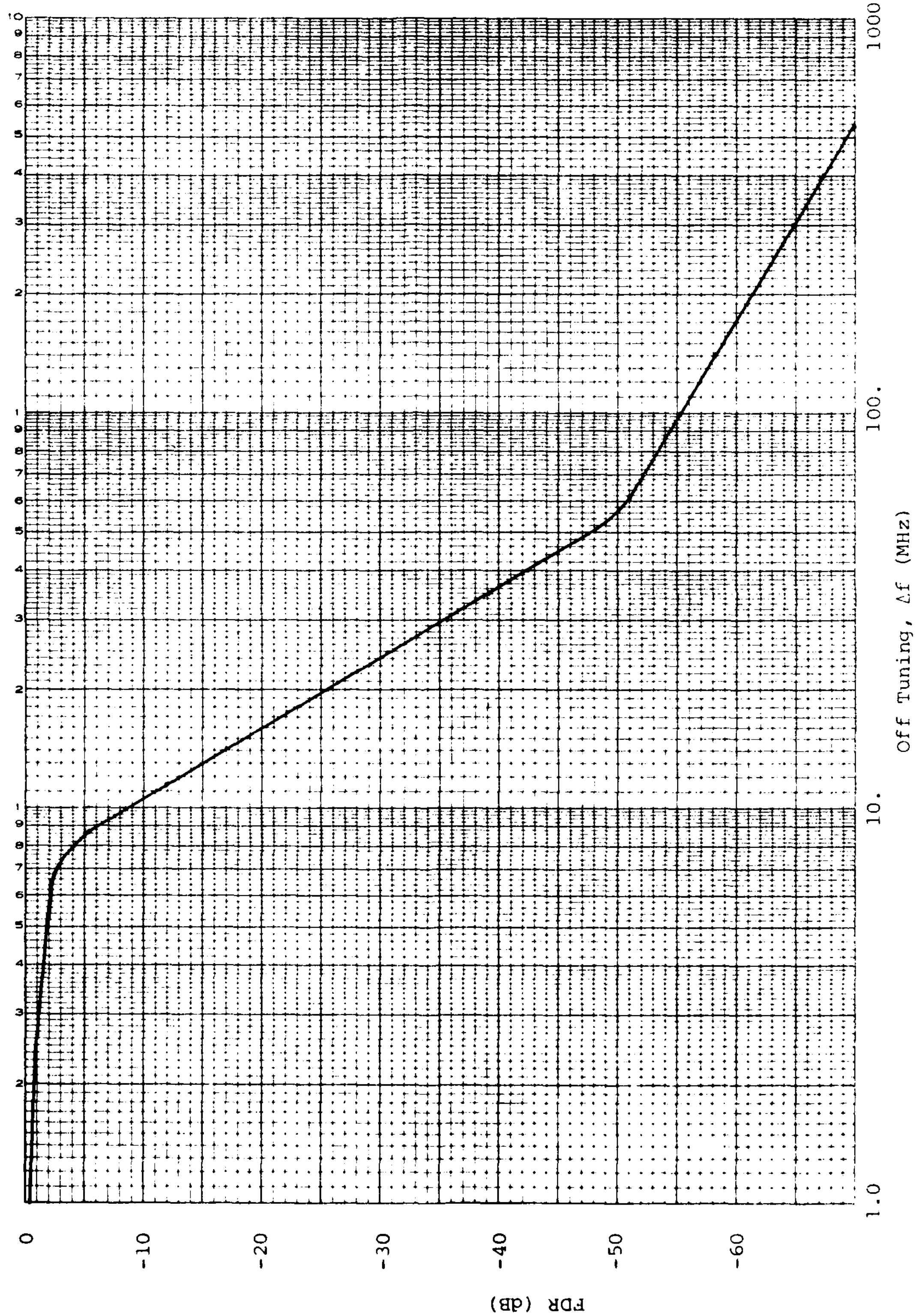

Figure F-4. FDR for the combination of the DME interrogator and the GPS preamplifier.

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